

# Data Communication Network at the ASRM Facility

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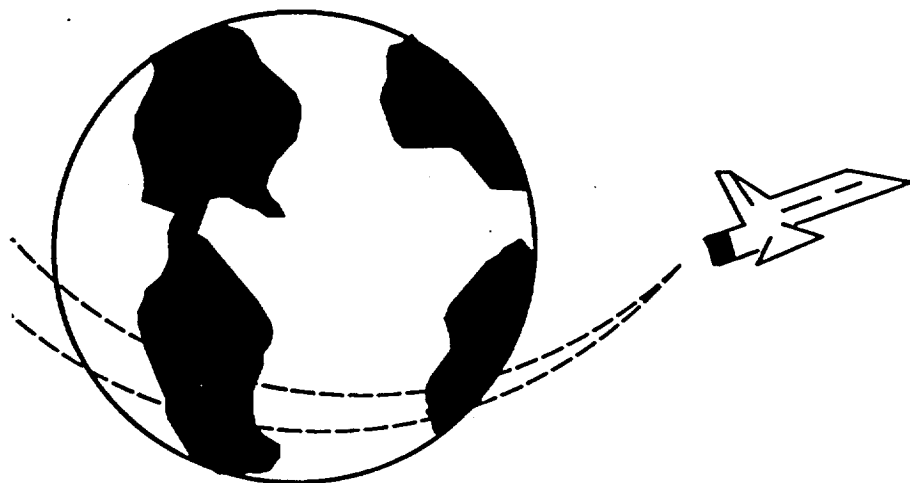
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**Robert J. Moorhead II**  
**Wayne D. Smith**  
Principal Investigators

**Ravi Nirgudkar**  
**James Dement**  
Research Assistants

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Department of Electrical and Computer Engineering

Mississippi State University

Mississippi State, MS 39762

(601) 325 - 2850

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## ABSTRACT

This report describes the simulation of the overall communication network structure for the Advanced Solid Rocket Motor (ASRM) facility being built at Yellow Creek near Iuka, Mississippi *as of today*. The report is compiled using information received from NASA/MSFC, LMSC, AAD, and RUST Inc. [1–8, 20–23].

As per the information gathered, the overall network structure will have one logical FDDI ring acting as a backbone for the whole complex. The buildings will be grouped into two categories viz. manufacturing intensive and manufacturing non-intensive. The manufacturing intensive buildings will be connected via FDDI to the Operational Information System (OIS) in the main computing center in B\_1000. The manufacturing non-intensive buildings will be connected by 10BASE-FL to the OIS through the Business Information System (BIS) hub in the main computing center. All the devices inside B\_1000 will communicate with the BIS. The workcells will be connected to the Area Supervisory Computers (ASCs) through the nearest manufacturing intensive hub and one of the OIS hubs.

Comdisco's Block Oriented Network Simulator (BONeS) [10] has been used to simulate the performance of the network. BONeS models a network topology, traffic, data structures, and protocol functions using a graphical interface. The main aim of the simulations was to evaluate the loading of the OIS, the BIS, the ASCs, and the network links by the traffic generated by the workstations and workcells throughout the site.

# **1. INTRODUCTION**

The Advanced Solid Rocket Motor (ASRM) facility at Yellow Creek near Iuka, Mississippi is part of a National Aeronautics and Space Administration (NASA) program to substantially improve the flight safety, reliability, productivity, and performance of the space shuttle's solid rocket motors. The ASRM is a replacement for the current space shuttle Redesigned Solid Rocket Motor (RSRM).

The facility will be government-owned but contractor-operated. Lockheed Missiles and Space Company Inc., ASRM division (LMSC) is the prime contractor. The operation of the facility will be directed by the subcontractor Aerojet ASRM division (AAD); RUST International Corporation (RUST) is responsible for the engineering and construction of the facility. The development of the ASRM is expected to take about six years, with the first new motors planned for a shuttle flight in 1996.

## **1.1 ASRM Communication Network Structure**

The operations at the ASRM site will be performed in different buildings scattered over a large area. These buildings will be inter-connected other through a Local Area Network (LAN).

The buildings are classified as Manufacturing Intensive buildings and Manufacturing Non-Intensive buildings, depending on the type of operation performed within the building. There will be four Manufacturing Intensive hubs and three Manufacturing Non-Intensive hubs connecting the respective buildings to the Main Computing Center in Building 1000 (B\_1000). All the workcells will be connected to the nearest Manufacturing Intensive Hub.

Each Manufacturing Intensive hub will communicate with either the Operational Information System (OIS) or an Area Supervisory Computer (ASC) via a Fiber Distributed Data Interface (FDDI) protocol over an optical fiber link. The workstations

will interact with the OIS, while the workcell's data will be routed to the ASCs. Each Manufacturing Non-Intensive hub will communicate with the Business Information System (BIS) by Ethernet protocol over an optical fiber link.

The two VAX computers in the OIS VAX cluster can communicate directly with each other and can even perform load sharing if required. The BIS on the other hand is a single entity. All the printer jobs throughout the campus will be routed through the Gandalf Terminal Server by the BIS.

For all this data transfer, the required routing, security, and flexibility will be provided by the Cabletron Multi Media Access Centers (MMACs) which will be used throughout the campus. The overall network logically forms one large FDDI ring although physically it appears to be a combination of various point-to-point connections.

## **1.2 Summary Of The Forthcoming Chapters**

The main aim of this report is to present the overall communication network structure for the ASRM facility. The report is composed of chapters discussing the ASRM Communication Network structure, the Cabletron devices and the BONEs models used for simulation.

The chapter on 'ASRM Communication Network Structure' concentrates on the network connectivity, cabling, and the different protocols used. That chapter also explains the flow of data in the network.

The chapter on 'Cabletron Devices Analysis' presents a detailed study of the Cabletron devices used at the ASRM site. The chapter on 'BONEs Modeling' gives an overview of the BONEs simulator. That chapter also describes the different BONEs models developed to simulate the ASRM environment.

The 'Conclusion' chapter at the end of the report comments on the network expectations and the network evaluation parameters. The chapter also summarizes



the various plots of Mean Delay and Throughput versus Traffic Intensity. Lastly an attempt is made to verify and validate the simulation.

### **1.3 Research Objective**

The main objective of the research will be to simulate and analyze the network to determine its performance under different load conditions. Comdisco's Block Oriented Network Simulator (BONeS) will be used for network simulation. The performance of the network with the given topology and protocols can be evaluated using BONeS. The two primary evaluation parameters that will be used to judge the network performance will be the throughput and the delay.

The aim of the simulations will be to look into the loading of the OIS, the BIS, the ASCs, and the network links due to the traffic generated by the workstations and the workcells over the entire site.

## 2. ASRM COMMUNICATION NETWORK STRUCTURE

### 2.1 Main Computing Center

Building 1000 (B\_1000) will provide an efficient means to plan and control the manufacturing of solid rocket motors for the ASRM project. All the workstations and the workcells communicate only with the OIS, the BIS, and the ASCs in B\_1000; there is no peer-to-peer communication required. B\_1000 also provides a link between the business functions and the manufacturing functions of the facility. The interconnection between the devices in B\_1000 is shown in Figure 2.1.

The OIS will be a VAX cluster consisting of two VAX 6000 computers, each with one FDDI adapter. In addition to this OIS VAX cluster, there will be two VAX 4000 computers, each with one Ethernet adapter. The BIS will be a VAX cluster consisting of one VAX 6310 and two VAX 6420 computers. Each of the ASCs will be a VAX 4400 with an Ethernet adapter.

B\_1000 will also have a Gandalf Terminal Server. The Gandalf Terminal Server is a large terminal server with a multitude of ports. The Gandalf can support 12 separate Ethernet channels. The Gandalf Terminal Server is physically a cabinet 6 feet tall. It will be the *only* terminal server throughout the campus.

The OIS, the BIS, the ASCs, and the Gandalf terminal server in B\_1000 will be connected to the outside network complex by the Cabletron MMACs, the intelligent hubs. There will be a fiber connection between the OIS and the Cabletron hubs. There will be a copper connection between the BIS and its Cabletron hub, and between the ASCs, and their Cabletron hub. The Cabletron hubs provide the necessary security, routing, and redundancy.

In addition to the devices already mentioned, Building 1000 will have nine more Cabletron hubs distributed in two switch rooms (viz. 507 and 638). B\_1000 will also

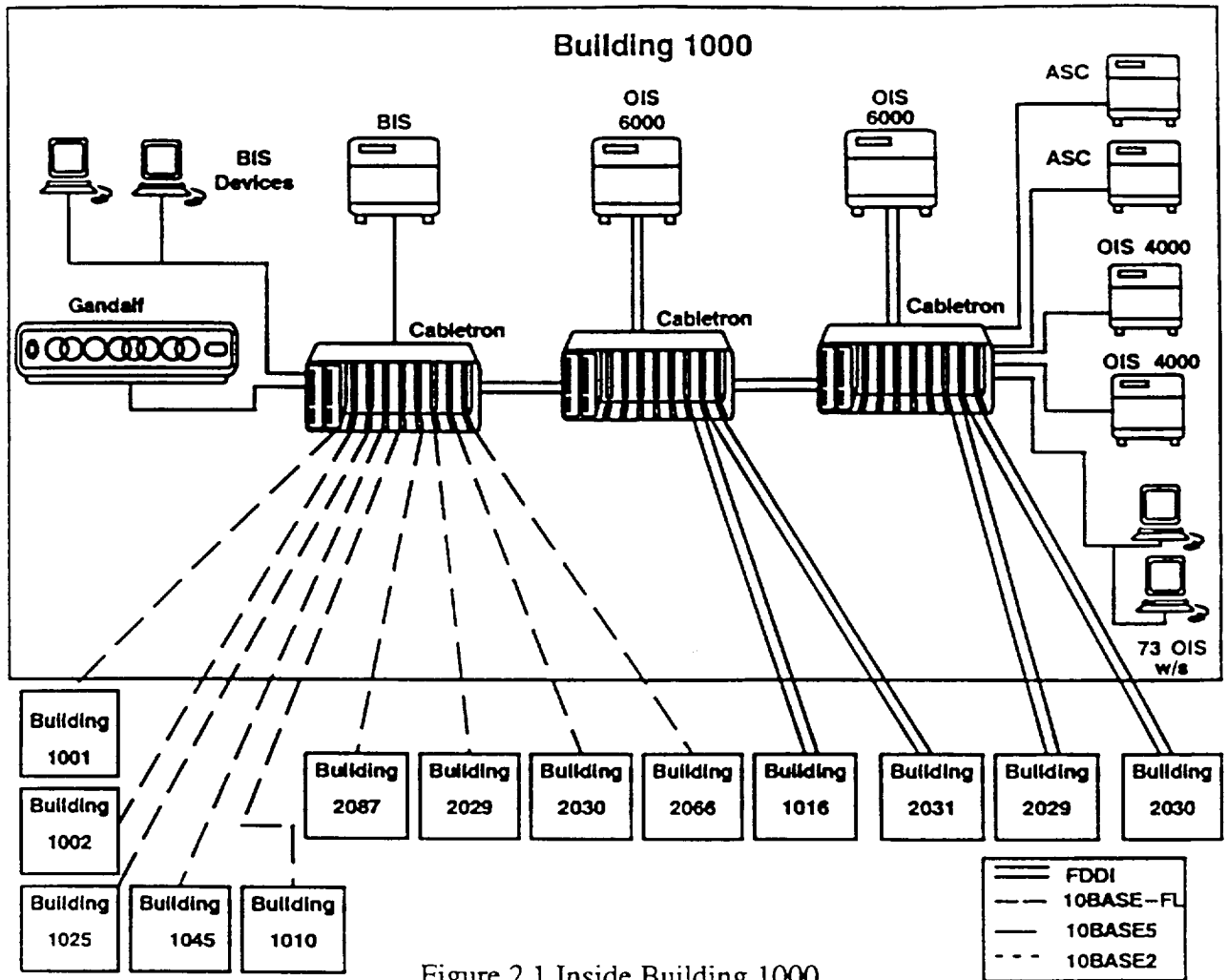


Figure 2.1 Inside Building 1000

have 32 printers, 25 CAD workstations, 400 Macintosh computers connected to the BIS hub by 10BASET, 50 PCs connected to the BIS hub by 10BASET, 31 Engineering workstations on 10BASE2, 289 dumb terminals connected via Asynchronous Data Interface (ADI) to the Gandalf to the BIS hub, and a connection to the PSCNI router.

## 2.2 Network Cabling at the ASRM site

At the ASRM site all the outdoor cabling and much of the indoor cabling will be optical fiber. Thin-wire and thick-wire coaxial cable will be used in B\_1000. Twisted pair will be used in manufacturing non-intensive buildings.

### **2.2.1 Outdoor Cabling At The ASRM Site**

All the outdoor cabling will be optical fiber. All optical fiber will be 62.5 / 125 micron multimode optical fiber. The outdoor cabling will support the FDDI standards for installation methodology and signal loss. There will be no outside splicing of the fiber, and all the indoor splicing will be done by fusion.

Every FDDI hub will have at least three redundant paths, viz. Channel A and Channel B of FDDI and a 10BASE-FL backup. Also every FDDI hub will have two redundant dual rings.

### **2.2.2 Manufacturing Intensive Buildings Connections**

The manufacturing intensive buildings will have two FDDI data paths from the B\_1000 with automatic switchover. One data path will be buried, while the other will be aerial. Buildings 1016, 2029, 2030, and 2031 are the manufacturing intensive buildings; each will have a hub directly connected to a hub in B\_1000. Buildings 2060 and 2076 will be connected to the hub in building 2029. Each hub will receive two pairs of fibers from the outside cable plant. All workstations and workcell devices will receive two fibers each from the respective hubs.

### **2.2.3 Manufacturing Non-Intensive Buildings Connections**

All the manufacturing non-intensive buildings in the complex will receive two fibers for its hub via the outside cable plant. All the workstations inside the buildings will get two fibers each from the respective hub.

### **2.2.4 Indoor Cabling At The ASRM Site**

For the indoor cabling in the manufacturing intensive buildings, the 10BASE-FL protocol will be used, mainly because it allows lower light levels and 16 redundant data paths, in addition, the Cabletron devices support the 10BASE-FL protocol.

### **2.2.5 Telephone Cabling**

The telephone system at ASRM Iuka is being built around an Intecom S/80 switch. The only overlap in the voice and data networks is between the Gandalf terminal server and the RS-232 devices it serves. The Intecom system will be used as the network for communicating serial information between the aforementioned devices. The RS-232 devices consist of printers and some workcells. The Intecom network's characteristics were studied and reported last year [19].

### **2.2.6 Physical Distances**

Table 2.1 gives the physical distance of all the buildings from the nearest hub. Table 2.2 gives the physical distance of all the hubs from B\_1000.

Building No.	Building Name	No. of workstns	No. of workcells	Link	Nearest Hub	Distance from hub(feet)
1000	Engineering / Computer	73	00	—	1000	—
1001	Security and Medical	03	00	Link #4	1000	1500
1010	Central Warehouse	10	00	Link #4	1000	600
1012 / 2087	Warehouse 'A'	14	00	Link #7	1012	—
1016	Case Prep. and Refurbishment	27	16	Link #3	1016	—
1022	Chemical Storage	01	00	Link #4	1000	2600
1025	Carpenters Shop	01	00	Link #4	1000	2400
1032	Office	03	00	Link #5	2066	800
1045	Training Center	04	00	Link #4	1000	1400
2028	Tool Clean / Core Prep.	08	00	Link #1	2029	2600
2029	Remote Control Room	12	01	Link #1	2029	—
2030	Non Destructive Evaluation Facility	03	02	Link #6	2030	—
2031	Final Assembly	15	00	Link #2	2031	—
2042	Main Motor Storage	04	00	Link #6	2030	8650
2060	Small Scale Propellant Proc.	04	02	Link #1	2029	2250
2066	Quality Assurance Lab.	05	00	Link #5	2066	—
2070	Sample Preparation	01	00	Link #5	2066	1450

Building No.	Building Name	No. of workstns	No. of workcells	Link	Nearest Hub	Distance from hub(feet)
2076	Qualification Motor Facility	04	01	Link #1	2029	2550
2082	HTPB Storage Tank Farm	01	00	Link #1	2029	850
3003	Deload – Open area No Building	00	01	Link #6	2030	7050
3005	Control Building	03	01	Link #6	2030	5950
3010	Incinerator System Building	00	01	Link #6	2030	4950
3011	Feed Prep. Facility	01	01	Link #6	2030	6600
4001	Shipping Dock	01	00	Link #6	2030	9700
	<b>TOTAL</b>	<b>184</b>	<b>26</b>			

Table 2.1 Distances of each building from the nearest hub

<b>Link</b>	<b>Distance (feet)</b>	<b>Number of Workstations on the link.</b>	<b>Number of Workcells on the link.</b>	<b>Type of the Link</b>
Link # 1 : (2029)	6700	28	04	Intensive and Non-Intensive
Link # 2 : (2031)	4650	15	00	Intensive
Link # 3 : (1016)	1450	27	16	Intensive
Link # 4 : (1000)	00	(19+73)	00	Non-Intensive
Link # 5 : (2066)	3550	09	00	Intensive and Non-Intensive
Link # 6 : (2030)	5000	12	06	Intensive and Non-Intensive
Link # 7 : (1012)	950	14	00	Non-Intensive

**Table 2.2 Distances of each hub from B\_1000**



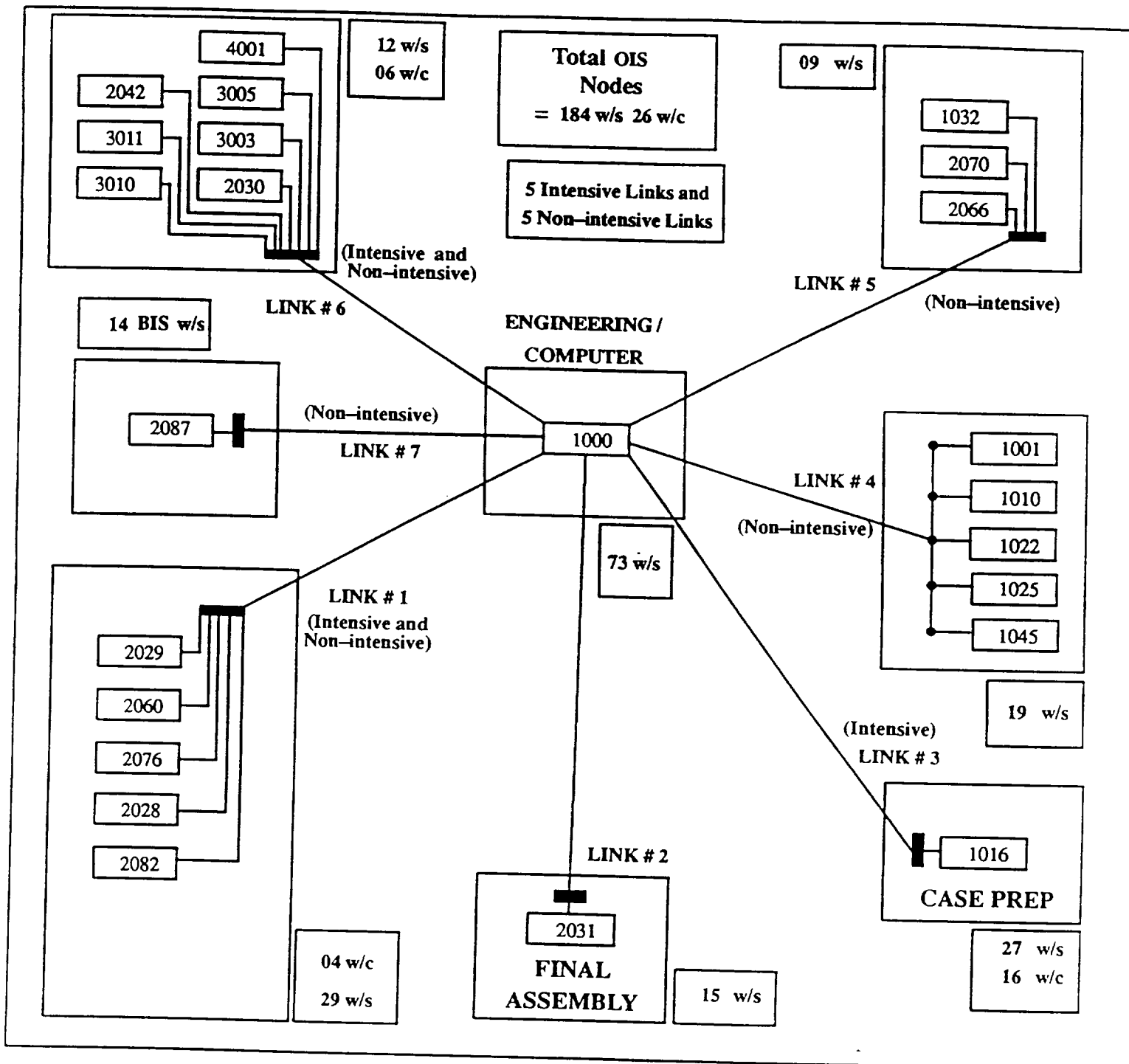


Figure 2.2 Hub Connections

## **2.3 Protocols used at the ASRM site**

For the communication network at the ASRM site, two protocols are specified, FDDI and CSMA/CD. All the manufacturing intensive buildings will be connected to B\_1000 by links with FDDI protocol, and all the manufacturing non-intensive buildings will be connected to B\_1000 by links with 10BASE-FL protocol (i.e. CSMA/CD on optical fiber). The protocol inside the manufacturing intensive building will be 10BASE-FL and the protocol inside the manufacturing non-intensive building will be 10BASE-T (i.e. CSMA/CD on twisted pair).

## **2.4 Data Rates for the Workstations and the Workcells**

### **2.4.1 Data Rate For The Workstations**

The data rate for the workstations can be computed by assuming that the workstation will be sending a block of data such as a text or graphics screen. A page of graphics is assumed to be 640 pixels by 480 lines with 16 colors. The data to be transmitted is given as 1920 characters / screen [4] which is equal to 192 kilobytes of data. The number of packets required to send 192 kilobytes can be calculated using 64 byte packets (worst case design). The delay per graphics page can be calculated by multiplying the number of packets by the mean delay per packet.

### **2.4.2 Data Rates For The Workcells**

The data rates for the workcells are computed using the information obtained [2] and is tabulated in Table 2.3 below. The information regarding workcell ID number and type of workcell for few workcells is still unavailable. The corresponding sections in the table are kept blank.

Building No.	Workcell ID #	Description	Workcell Type	Data Rates	Duration
B_1016	W 102	Robotic washout station	MFG	441.6 bytes/sec	24 hrs
	W 104a	Hydrotest equipment	Testing	15.66Mbytes/sec	8 min/day
	W 104b	Hydrotest data acquisition system	Testing	15.66Mbytes/sec	8 min/day
	W 107	Electromag-acoustic eddy current test	NDE	533 bytes/day	16hrs / 3 days
	W 114	Robotic dimensional inspection	NDE	1.44 Mbytes/day	12 hrs/ 3 days
	W 116	Aqueous degreaser	MFG	384 bytes/sec	8 hrs
	W 117	Robot clean/paint/osee	MFG	364.8 bytes/sec	40 hrs/ 5 days
	W 118	Plastic media blast robot	MFG	105.6 bytes/sec	16 hrs/ 5 days
	W 121	Clean, dry, liner robot	MFG	604.8 bytes/sec	16 hrs/day
	W 148	Horizontal elastic insulation application	MFG	268.8 bytes/sec	60 hrs/ 5 days
	W 149	Pattern cutting station	MFG	720 bytes/sec	4 hrs/day
	W 159	Aqueous degreaser	MFG	384 bytes/sec	8 hrs
	W 160	Plastic media blast robot	MFG	652.8 bytes/sec	8 hrs/ 5 days
	W 161	Component Washout Robot	MFG	182.4 bytes/sec	8 hrs/ 5 days
	W 168	Ultrasonic inspection	NDE	533 bytes/day	16 hrs/ 3 days
	W 169	Autoclave (insulation curing)	MFG	86.4 bytes/sec	40 hrs/ 5 days
B_ 2029	DCS	Mix/Cast distributed control system	MFG	960 bytes/sec	96 hrs/ 1 month
B_2030	W 402	Real time radiography	NDE	800 bytes/ hr	40 hrs/ 3 days
	W 403	Ultrasonic test	NDE	800 bytes/ hr	24 hrs/ 3 days
B_2060	WSSP	Small scale propellant		768 bytes/sec	constant
		Scales		18816 bytes/day	constant

Building No.	Workcell ID #	Description	Workcell Type	Data Rates	Duration
B_2076	MTRQ	Motor qualification data acquisition system		576 Kbytes/sec	8–12 min/day
B_3003		Propellant removal station	MFG	441.6 bytes/sec	24 hrs
B_3005		Thermal treatment control	MFG	384 bytes/sec	8 hrs
B_3011		Feeder preparation	MFG	384 bytes/sec	8 hrs
B_3010		Incinerator	MFG	384 bytes/sec	8 hrs

Table 2.3 Workcells and their data rates

## 2.5 Data Flow over the Network

### 2.5.1 Manufacturing Intensive Buildings

The manufacturing intensive buildings will have FDDI data paths from B\_1000. Buildings 1016, 2029, 2030, and 2031 are the manufacturing intensive buildings, and each will have a hub directly connected to an OIS hub in B\_1000. The workstations in these buildings will be communicating with the OIS 6000 computers. The workcells in these buildings will communicate via the OIS hub with the two ASCs.

### 2.5.2 Manufacturing Non-Intensive Buildings

The manufacturing non-intensive buildings 1001, 1002, 1010, 1025, and 1045 will have 10BASEFL data paths from B\_1000. All other manufacturing non-intensive buildings will be connected to B\_1000 through the nearest manufacturing non-intensive hub in buildings 2029, 2066, and 2030. The workstations in all the manufacturing non-intensive buildings will communicate via the BIS hub using two OIS 4000 computers.

### **2.5.3 BIS Devices**

All the BIS devices inside B\_1000 will communicate through the BIS hub with the BIS VAX cluster. The BIS VAX cluster will consist of three VAX computers, one VAX 6310 and two VAX 6420 computers.

### **3. CABLETRON DEVICES**

The network structure of the entire ASRM complex consists of many separate networks [29]. The networks make use of different types of transmission media as well as different communication protocols. Cabletron Multi Media Access Centers (MMACs), known as intelligent hubs, are used to interconnect the individual networks. The MMACs allow Ethernet, Token Ring, and FDDI networks to be connected together regardless of the transmission media (Fiber, Twisted Pair, Coax, etc.) that is used [24]. The following sections describe the individual components that make up the MMAC as well as giving some important characteristics of each of the components.

#### **3.1 Components of the MMAC**

The MMAC is made up of a chassis, power supply module(s), and a combination of Media Interface Modules (MIMs) with at least one Management / Repeater Module. The individual components used in the ASRM MMACs are described in more detail in the following sections. (Although Cabletron manufactures over 50 modules for use with their MMAC, only the modules that pertain to the ASRM network will be discussed.) The following list gives the module name and the section in which it is discussed:

- 3.1.1 MMAC-M8FNB – The MMAC Chassis
- 3.1.2 Power Supply Modules
- 3.1.3 EMME – Ethernet Manager
- 3.1.4 FORMIM – Fiber Optic Repeater Module
- 3.1.5 CXRMIM – Coaxial Repeater Module
- 3.1.6 TPRMIM – Twisted Pair Repeater Module
- 3.1.7 FDMIM – FDDI Management / Bridge Module
- 3.1.8 MT8-MIM – Ethernet Concentrator Module
- 3.1.9 GX-M MIM – LocalTalk to Ethernet Concentrator / Bridge

### **3.1.1 The MMAC Chassis**

The MMAC chassis is a modular unit that is used to hold the individual modules that make up the complete MMAC. Cabletron manufactures three different models of the chassis; they are referred to as the MMAC-3FNB, 5FNB, and M8FNB, which contain slots for three, five, and eight media modules respectively. The MMAC-M8FNB, the only chassis used at the ASRM site, can provide up to 168 Ethernet ports [24]. The first slot in each chassis must be populated with a Management / Repeater Module such as the EMME (See Section 3.1.3).

Built into the back of the chassis is the backplane. Cabletron has developed a flexible backplane known as the Flexible Network Bus (FNB). Modules inserted into the chassis connect to this bus, and are then able to transmit and receive data on this bus. The modules can be “hot swapped”, which means the modules can be inserted and removed without powering down the entire MMAC.

The FNB consists of several smaller buses known as the Ethernet, Management, Power, and Token Ring / FDDI buses. The Ethernet bus is broken down even further into the Ethernet A, B, and C buses. However, only the newer generation of multi channel repeater modules such as the TPRMIM (See Section 3.1.6) can access the B and C Ethernet buses. Due to the flexibility of the FNB, the MMAC-FNB can be simultaneously populated with Ethernet, Token Ring, and FDDI modules.

### **3.1.2 Power Supply Modules**

The MMAC-M8FNB can contain up to two MMAC-M8PSM power supply modules. The power supply modules, like the other media modules, are “hot swappable” so they can be removed and installed without affecting the network communications. Using the FNB, the power supplies are capable of load sharing. That is, when the traffic on a single MMAC becomes intense, the power supply modules will share the workload reducing the stress on each supply.

Another advantage of the dual power supplies and the FNB, is that when a power supply module malfunctions, the other supply carries the full load. In this situation, network communications is unaffected, and the Management / Repeater module will notify the network manager of the failed power supply.

### **3.1.3 EMME**

The first slot in each MMAC must be populated with a Management / Repeater Module [30]. The MMACs used at the ASRM site will all contain the EMME which is a new generation Ethernet Bridge and Management Module. The new generation modules are capable of accessing the internal B and C Ethernet buses. The EMME bridges the internal Ethernet buses A, B, and C to the external Ethernet bus D. Ethernet bus D is the bus that connects to the front panel of the EMME.

The EMME is also capable of filtering traffic that passes over the bridge. Using an internal Source Address Database (SAD) that is capable of storing up to 8,191 Ethernet addresses, the EMME filters out packets whose destination does not reside on the opposite side of the bridge. This reduces the amount of traffic flowing across the bridge thereby reducing the load on the entire LAN. The database is "self learning" and has a user configurable aging delay so that addresses that have not been active for a specified amount of time can be removed.

The EMME was specifically designed to operate in a multiple bridge environment by using the Spanning Tree Algorithm [26]. The EMME is assigned a Bridge ID which is computed from the bridge address and the bridge priority. The bridge priority, or Root Cost, is assigned by the network administrator. This is just a cost that is compared against the Root Cost of other bridges in the network [34]. The Spanning Tree Algorithm (STA) uses this cost to determine the Root Bridge. By editing this Root Cost, the administrator can influence the selection of the root bridge. Using the STA, network designers can set up a fault tolerant network by putting bridges in parallel for



backup paths. The STA detects potential data loops and lets the network administrator select a root bridge and determine the most efficient data paths.

### **3.1.4 FORMIM**

The Fiber Optic Repeater Media Interface Module (FORMIM) is a multi-channel 10BASE-FL repeater card [24]. Multi-channel simply means that the module is capable of accessing the FNB (Ethernet channels B and C). The FORMIM-22 features 12 fiber optic ports with ST connectors mounted on the front panel.

Using the multiple internal Ethernet buses, this advanced Repeater Module can support two additional fully functional Ethernet networks within the same MMAC. The EMME described above is used to bridge these networks to the other existing Ethernet networks.

The FORMIM-22 utilizes the advanced Repeater Interface Controller (RIC) chip to provide full IEEE 802.3 compliant repeater capabilities to each port and each module on the MMACs internal Ethernet channels. The RIC chip was co-developed by Cabletron and National Semiconductor.

All multi-channel repeater modules that utilize the RIC chip (RMIMs) can be configured by either software or hardware to operate in one of two modes. These modes are Ethernet B, Ethernet C, or Standalone. In the Standalone mode, the RMIMs repeat packets independently between ports on the same module and modules on the same bus (B or C) using the RIC chip. This relieves some of the repeating load from the EMME. Seven separately repeated Ethernet segments can be obtained using the MMAC-8FNB and seven RMIMs operating in the Standalone mode.

### **3.1.5 CXRMIM**

The Coaxial Repeater Media Interface Module (CXRMIM) is the same as the FORMIM described above except that the 12 fiber optic ports (10BASE-FL) on the front panel are replaced by 12 thin wire coax ports (10BASE-2) with BNC connectors.

In addition to the coax connectors, the CXRMIM also provides a user definable Ethernet Port Interface Module (EPIM) that permits users to configure the module with a single port for a variety of media types. Network designers can choose from seven different types of EPIMs including an AUI module, a CXRMIM standard feature, and optional modules supporting twisted pair, fiber optic, and coax media. All EPIMs are “hot swappable” and can be inserted through the front panel of the CXRMIM.

### **3.1.6 TPRMIM**

Twisted Pair Repeater Media Interface Modules (TPRMIMs) are fault tolerant Multi-Channel 10BASE-T modules. The TPRMIM-33 and TPRMIM-36 provide 13 and 26 10BASE-T connections respectively. The TPRMIM-33 uses one RJ71 (50-pin Telco) connector to provide 12 10BASE-T twisted pair connections where TPRMIM-36 uses two RJ71 connectors to provide 24 twisted pair connections.

Each TPRMIM provides the user with one Ethernet Port Interface Module (EPIM) (See section 3.1.5 above for a description of the EPIM). In addition to its EPIM and two RJ71 connectors, the TPRMIM-36 provides an additional Access Unit Interface (AUI) connection for an external transceiver.

### **3.1.7 FDMMIM**

The FDDI modules manufactured by Cabletron Systems provide high performance Ethernet to FDDI bridging, as well as FDDI concentrator capabilities. These features allow for designs that include Ethernet to the desktop and FDDI to the desktop from the same MMAC [24].

The FDDI Management Media Interface Module (FDMMIM) is the first single channel module discussed so far. In fact, all the modules in the following discussions will be single channel modules. Unlike the multi-channel Ethernet modules, single channel modules do not have the ability to access the FNB bus (Ethernet buses B and C). The FDMMIM is a full performance Ethernet to FDDI bridge module. It provides

the connections between a 10 Mbps Ethernet network (regardless of the number of nodes or media type), and a 100 Mbps FDDI backbone.

The FDMMIM connects to the FDDI network via two MIC connectors on the front panel. In the event that one of the FDDI rings is severed or broken in some other manner, the FDMMIM will automatically "wrap" to the secondary ring to continue communication. The FDMMIM also provides for an optical bypass switch. This is an external passive device which will provide optical continuity in case of power or other node failure.

To communicate with the Ethernet network, the FDMMIM communicates with Ethernet bus A on the MMAC backplane. Through this bus, the FDMMIM can communicate with every Ethernet module in the chassis. This limits the number of Ethernet connections through the same FDDI module only by the number of Ethernet connections installed in the MMAC.

Since the FDMMIM is also a management module, it has a modem and console port on the front panel like the EMME that was discussed earlier. Through these ports, the FDMMIM can be software configured and can provide diagnostic information just like the EMME. Also, like the EMME, the FDMMIM is designed for a multiple bridge environment and therefore supports the Spanning Tree Algorithm (STA).

The FDMMIM-04 has all of the features of the FDMMIM described above, but also contains four concentrator ports for FDDI connections. The four concentrator ports are provided by the additional four MIC connections located on the front panel. Using the concentrator ports, up to four Single Attached Stations can be connected to the FDDI backbone.

### 3.1.8 MT8-MIM

The MT8-MIM coaxial concentrator module provides eight male Ethernet / IEEE 802.3 Access Unit Interface (AUI) transceiver attachments. Each of these AUI

attachments can be connected to the AUI port of any network device. The MT8-MIM is a manageable module which provides all the functionality of a multiport transceiver, yet integrates into the MMAC chassis.

### **3.1.9 LocalTalk to Ethernet Router / Repeater Module**

Macintosh computers communicate using a LocalTalk network. The GatorMIM CS is a high-performance LocalTalk router module for the MMAC that provides connectivity between LocalTalk, Ethernet, and DECNet with no configuration required. The GatorMIM module will also function as a TCP/IP gateway that allows LocalTalk-based Macintoshes to be combined with highly complex TCP/IP networks.

The GatorStar integrates a 24-port LocalTalk repeater with a high-performance LocalTalk to Ethernet router with the GatorMIM functionality. The GatorStar GX-M allows a LocalTalk network with up to 96 directly connected Macintosh users to communicate with UNIX, Digital / Path Works, and PC users on Ethernet. Internal smart repeater technology provides automatic detection and correction of "jabbering" on LocalTalk ports and determines the location of individual nodes for each port.

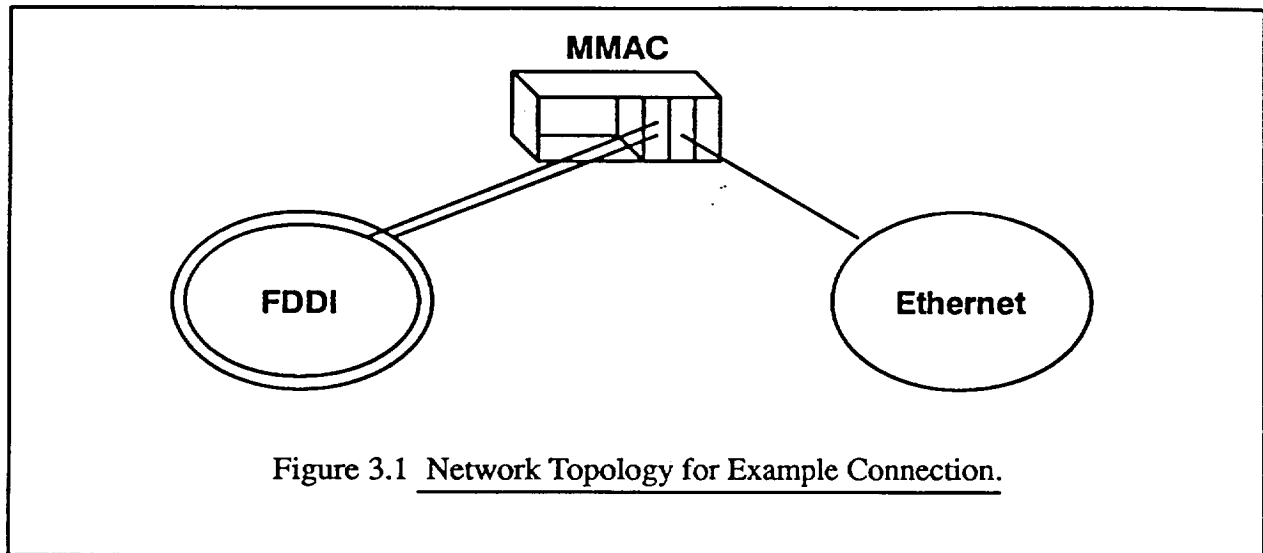
### **3.2 Filtering and Forwarding Characteristics of the Cabletron MMACs**

The EMME modules used in the ASRM MMACs provide multiport bridging at "wire speed," network to network. The EMME documentation states that the EMME filters Ethernet packets at the rate of 28,000 pps (packets per second) and is capable of forwarding data at up to 20,000 pps [30]. The FDMMIM modules used in the ASRM MMACs are capable of filtering and forwarding Ethernet packets at up to 14,880 pps [34].

### **3.3 Example Connection**

In order to more fully understand how the MMAC operates, we will examine in detail the process by which a Cabletron MMAC is used to solve a typical networking requirement. The following sections describe the current networking requirement, the

MMAC modules used to satisfy the requirement, and how the modules interact with each other. Figure 3.1 shows a diagram of the network topology for this example.



### 3.3.1 Typical Networking Requirement

Within the network structure of the Advanced Solid Rocket Motor (ASRM) facility located at Iuka, Mississippi, there is a need to connect a 10BASE-FL Ethernet network to a FDDI backbone. The Ethernet side of the network will require connections for 12 workstations which are 10BASE-FL compliant. Although this example uses the 10BASE-FL Ethernet media type, any Ethernet MIM manufactured by Cabletron would function in the same manner. Since we are connecting a Ethernet network to a FDDI backbone, the MMAC will be configured in a routing, as opposed to a bridging, configuration.

### 3.3.2 Equipment Selection

Before we can decide on what chassis will be required, we must determine the modules that will be used. This is necessary because the number of modules and the

power requirements of each module must be considered when selecting a chassis and the power supplies.

### **3.3.2.1 10BASE-FL Connection**

In the requirements section, it was stated that we need to connect 12 10BASE-FL Ethernet workstations together. The Cabletron FORMIM-22 (Fiber Optic Repeater Media Interface Module) allows up to 12 10BASE-FL connections. Since the FORMIM is a multi-channel module, it can make use of the FNB. This means that we can configure the module to run on either the B or C Ethernet Buses. Using a Ethernet Management Module (discussed below), it is possible to selectively route traffic from one network to the other.

### **3.3.2.2 FDDI Backbone Connection**

In order to bridge the FDDI backbone to the Ethernet network, we need a Ethernet to FDDI Bridge. Cabletron manufactures a module known as the FDMMIM (Fiber Distributed Management Media Interface Module) for this purpose. A FDMMIM is capable of filtering and forwarding Ethernet packets at rates up to 14,880 pps, and FDDI packets at rates up to 446,420 pps. A Source Address Table capable of storing 8,191 source addresses allows the FDMMIM to selectively prevent traffic from crossing the bridge. This reduces the traffic load on both the FDDI and Ethernet sides of the bridge thereby reducing the load on the entire network.

The FDMMIM connects to the FDDI backbone through two MIC connectors located on the front panel. Since the FDMMIM attaches to both the primary and secondary rings of the FDDI backbone, the module can "wrap" to the secondary counter-rotating ring. This allows the FDMMIM to restore the connection in case a link or node in the ring is for any reason severed. In addition, there is an Optional Optical Bypass Switch that can be installed.

To communicate with the Ethernet modules, the FDMMIM module connects to the Ethernet backplane (Ethernet Bus A). By connecting to this Ethernet bus, the FDMMIM is capable of communicating with every Ethernet module in the MMAC.

### **3.3.2.3 Bus Management**

In order to forward traffic from either Ethernet Bus B or C to Ethernet Bus A, we need a management module. Since we are using the FORMIM, which utilizes the FNB, we must use a management module that is also capable of accessing this bus. Cabletron has developed the EMME Ethernet Management Module to provide this service. The EMME is capable of routing traffic between all four Ethernet channels (A,B,C, and D). The EMME, like the FDMMIM is capable of storing up to 8,191 source addresses in its Source Address Table. Unlike the FDMMIM, which can only filter and forward traffic at 14,880 pps, the EMME can filter and forward traffic at 28,000 and 20,000pps respectively.

### **3.3.2.4 Chassis Selection**

Now that we have selected the three modules that we will be using, we must select the chassis that they will be put in. The MMAC-3FNB is capable of storing one management module (such as our EMME), and two other MIMs. This chassis will therefore hold all the modules that we have chosen for this example. However, the number of cards is not the only criteria that must be kept in mind. The power supply must also be considered. By adding up the amperes required by each module, it can be determined what power supply must be used. The amperes provided by the power supply (or supplies) must exceed that required by the sum of the MIM modules. In order for a two unit power supply MMAC to provide power redundancy, each power supply should be rated at a greater amperage than the sum of the modules.

Although the MMAC-3FNB provides us with enough module slots to do the job, it does not provide us with any room for expansion. All of the chassis used at the ASRM facility are MMAC-8FNBs, this allows maximum flexibility for future expansion.

### **3.3.3 Installation of Modules**

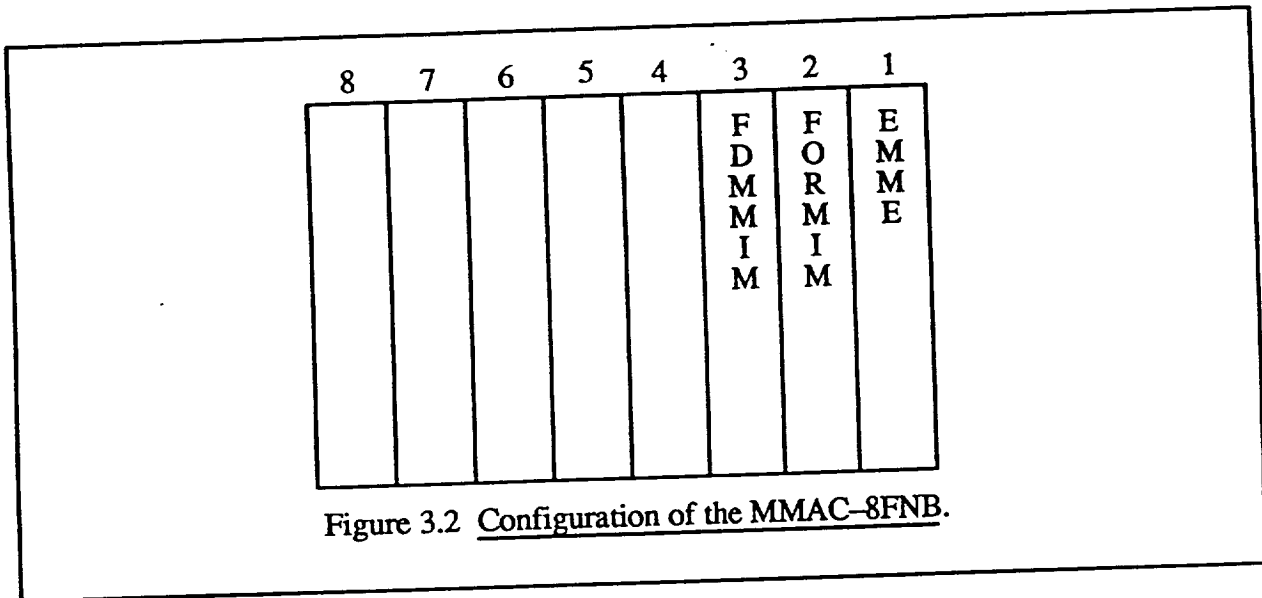
The first slot in the MMAC, slot one, is reserved for Management/Repeater modules. If the customer does not require management or bridging functions however, it is possible to configure a MMAC hub such that slot one is left empty. However, in order to bridge the FORMIM module (FNB Channel C) to the FDMMIM module (Ethernet Bus A), we must use the EMME. In addition to this bridging, the EMME gives us the capability to run remote network managers by which we can configure the modules via software. Therefore the EMME should be installed in the first slot.

If there are to be any RMIMs used, and they are to be controlled by the EMME, they must be placed immediately following the EMME. The RMIMs are capable of sensing whether or not the module to their left is another RMIM. The first RMIM that does not detect another RMIM to its left, terminates the B and C data buses on the FNB. By terminating these data buses, the FNB is freed up to be used by FDDI and Token Ring Modules. Before the FORMIM is installed, it must be told which mode to operate in. The FORMIM can operate in either Ethernet Bus B, Ethernet Bus C, or in the standalone mode. Configuration can be accomplished through either hardware or software. Even if it is planned to use the EMME to set the mode by software, it is necessary to set a default mode with hardware. Two jumpers on the side of the module are used to select the operating mode. After this configuration is complete, the module can be inserted into slot two, adjacent to the EMME.

The third and final module to be inserted is the FDMMIM. Like the FORMIM described above, there are hardware default settings that must be configured before the FDMMIM is installed. These options include: Forward/Filter broadcast packets,



STA On/Off, IEEE/DEC-NET Bridge protocol, and Designated Root/Not Designated Root. Once the initial configuration is complete, the module can be installed in the third slot, next to the FORMIM. The MMAC-M8FNB power supply module(s) are inserted into the back of the unit. The complete MMAC, viewed from the front, is shown in Figure 3.1.



### 3.3.4 Operation

When the MMAC is powered up, the FORMIM module notices that the module to its left is not another RMIM so it closes off the B and C Ethernet Buses. This opens up the C bus for the FDMIM module to use. Once the MMAC has gone through initialization, and is properly configured by the remote manager (if needed) it is ready for normal operation.

When an FDDI packet is encountered by the FDMIM module, the destination address is examined. If the FDMIM can determine by its Source Address Table (SAT) that the destination does not reside on this Ethernet network, it discards the packet. If, on the other hand, it can not determine where the destination is, it will forward the

packet to the EMME module. The EMME module then examines the packet to try and determine which bus it should be sent to. In our example, the only other network connected to the MMAC is an Ethernet network that is connected to the C bus. Therefore the EMME re-times the packet and puts it on the C bus where all modules connected to this bus (in our case this is only one) receive the packet.

In the other direction, an Ethernet packet enters the FORMIM. The FORMIM re-times the packet and puts it on the C bus. The EMME receives this packet, checks the destination address against its SAT, and forwards the packet as necessary. If the packet is forwarded, it is re-timed and put on Ethernet bus A where the FDMMIM receives it. The FDMMIM checks the destination against its SAT and if necessary, converts the Ethernet packet to the FDDI format, and then stores it in a buffer. As soon as the FDMMIM receives the FDDI free token, it will transmit as many of the packets in its buffer as it can during the allotted time.

In the two scenarios above, it can be seen that a forwarded packet is examined twice. The packet is examined once by the EMME and then again by the FDMMIM, and not necessarily in that order. The reason for this is not terribly obvious given our example. Given another situation however, where the MMAC contains two or more FDMMIMs, it is easy to see why the dual checking is needed. Each FDMMIM must check the packet to determine if it should be forwarded across its bridge. The same principle applies to the EMME. It is possible for the EMME to bridge up to four different Ethernet segments (A,B,C, and D).

### 3.4 Summary

In this chapter, we have examined the Media Interface Modules (MIMs) that populate the Multi Media Access Centers (MMACs) used at the ASRM facility. The functions and characteristics of each module were briefly discussed.

In addition, the requirements of a small example network were presented. Steps were taken to develop a MMAC configuration that would satisfy those requirements. Once the modules were selected, the steps to assemble the MMAC were given.

Finally, after having discussed the assembly of the MMAC, a basic overview of the operation of the MMAC was given. This overview did not cover how the MMAC is operated.

## 4. BONEs MODELING

### 4.1 BONEs Simulator

The Block Oriented Network Simulator (BONEs) provides an interactive graphical environment for simulation-based analysis and design of a broad range of communication networks. The integrated BONEs environment includes the capability to :

1. Graphically describe data structures in a hierarchical fashion.
2. Graphically describe protocol functions, node processing, and network topology in a hierarchical fashion using block diagrams.
3. Translate the network model into a C program, and execute an event driven simulation of the model.
4. Perform design iterations and tradeoff analysis.
5. Document both models and results.

BONEs provides an easy-to-use modeling and simulation environment, an excellent model library that is user extensible, and a set of powerful analysis tools. BONEs minimizes the amount of code the user has to write and provides on-line help, documentation aids, and error checking. These features free the user from the low level details of simulation programming and directs the focus on modeling, analysis, and design.

In the BONEs environment, the network model is specified in terms of the *network topology, traffic, packet and message (data) structures, and protocol functions*. The user constructs the network graphically and hierarchically using the building blocks from the BONEs model library. The user can also write the components of a model in C and incorporate them into the BONEs modeling environment. BONEs translates the network model into a C program, executes an event driven *Monte Carlo simulation*, computes statistical measures of network performance, and displays the results graphically.

## 4.2 Network Modeling using BONEs

Simulation model design consists of three elements : data structures, modules, and a system. The modules in BONEs control the flow of the data structures. Many basic modules are provided with BONEs, such as decision nodes, random traffic generators, and fixed delays. These can be combined to form new modules to meet the specific needs of the simulation.

BONEs is an event driven simulation. All events except traffic generators are triggered by a previous event called a *Trigger*. If a block is not triggered then there will be no output. Thus when building a model using the provided blocks, race conditions such as parallel inputs must be avoided. Instead, blocks should be cascaded to prevent the race conditions.

The different nodes that were constructed in this simulation are workstation and workcells. Models of other nodes, such as CSMA / CD nodes, FDDI nodes, and bridges are included in the BONEs library. The parameters of the CSMA / CD nodes are set to the IEEE 802.3 CSMA / CD standard. The packet size was set to the smallest possible size of 64 bytes for a worst case analysis. If the packet size is small the transmission time will be small, with respect to the propagation delay, and more collisions will occur.

A traffic source model was developed to model a workstation sending a block of data such as a text or graphics screen. The traffic source model sends a set number of packets at an interarrival rate set by the user. The interarrival rate has a Poisson distribution because traffic on a LAN tends to have a Poisson distribution.

## 4.3 Different BONEs Modules

The different BONEs modules developed for this simulation are as shown in Table 4.1 and 4.2.

<b>BONeS Module</b> (indicated in upper left on each figure)	<b>MMAC to which the module is connected</b>	<b>Devices in this module</b>	<b>Destination</b>
<b>ASRM Network</b>			
<b>MAC-Network</b>	MMAC in Switch Rm 210 in B_1000	80 MAC w/s.	3 modules to BIS 6310 and 2 modules to BIS 6420_A.
<b>B_2087</b>	Non-Intensive MMAC in B_1012	14 MAC w/s in B_1012	BIS 6420_A
<b>RM 507</b>	MMAC in Comp Rm 507 in B_1000	50 PCs, 7 SGIs with a server.	BIS 6420_B
<b>Printer-CAD-ENG</b>	MMAC in Switch Rm 210 in B_1000	25 CAD w/s with 5 servers, 31 ENG with 9 servers and 32 MAC printers.	BIS 6420_B
<b>RM 638A</b>	MMAC in Switch Rm 638 in B_1000	80 MAC w/s.	BIS 6420_B
<b>B_2029</b>	Non-Intensive MMAC in B_2029	8 w/s in B_2028 1 w/s in B_2082	OIS 4000_A
<b>B_2030</b>	Non-Intensive MMAC in B_2030	4 w/s in B_2042 3 w/s in B_3005 1 w/s in B_3011 1 w/s in B_4001	OIS 4000_A
<b>B_2066</b>	Non-Intensive MMAC in B_2066	3 w/s in B_1032 1 w/s in B_2070	OIS 4000_A
<b>RM 638B</b>	MMAC in Switch Rm 638 in B_1000.	Gandalf Terminal server.	OIS 4000_A
<b>OIS- Workstations</b>	MMAC in BIS Hub in B_1000.	73 OIS MAC w/s.	OIS 4000_B
<b>B_1001</b>	MMAC in BIS Hub in B_1000.	3 w/s in B_1001	OIS 4000_A
<b>B_1045</b>	MMAC in BIS Hub in B_1000.	4 w/s in B_1045	OIS 4000_A
<b>B_1010</b>	MMAC in BIS Hub in B_1000.	10 w/s in B_1010	OIS 4000_A
<b>B_1002</b>	MMAC in BIS Hub in B_1000.	1 w/s in B_1002	OIS 4000_A
<b>B_1025</b>	MMAC in BIS Hub in B_1000.	1 w/s in B_1025	OIS 4000_A

<b>BONeS Module</b> (indicated in upper left on each figure)	<b>MMAC to which the module is connected</b>	<b>Devices in this module</b>	<b>Destination</b>
<b>B_1016_C</b>	Intensive MMAC in B_1016	27 w/s in B_1016 16 w/c in B_1016	OIS 6000_A ASC_A
<b>B_2029_C</b>	Intensive MMAC in B_2029	12 w/s in B_2029 1 w/c in B_2029 4 w/s in B_2060 2 w/c in B_2060 4 w/s in B_2076 1 w/c in B_2076	OIS 6000_B ASC_B
<b>B_2030_C</b>	Intensive MMAC in B_2030	3 w/s in B_2030 2 w/c in B_2030 1 w/c in B_3003 1 w/c in B_3005 1 w/c in B_3010 1 w/c in B_3011	OIS 6000_B ASC_B
<b>B_2031_C</b>	Intensive MMAC in B_2031	15 w/s in B_2031	OIS 6000_A

Table 4.1 BONeS Modules for ASRM sub-networks

BONeS Module	Description
FORMIM-22	12 port 10BASE-FL
CXRMIM	12 port 10BASE2
MT8-MIM	8 port 10BASE5
TPRMIM-36	24 port 10BASET
GX-M	24 port LocalTalk
FDMMIM	Ethernet-FDDI Bridge
FDMMIM-04	4 port FDDI concentrator

Table 4.2 BONeS Modules for Cabletron MIMs

In addition to the above modules, the following basic modules were developed : BIS, ASC, OIS 4000, OIS 6000, workstation, and Printer. All the modules created for this project are shown in Appendix A.

#### 4.4 Probes Setting and the Simulation Iterations

Several probes were placed throughout the network to gather statistics during the simulation. The mean delay per packet, received throughput, transmitted throughput, and the number of completed packets were collected for each separate link. Each iteration interval was divided into ten batches in order to collect these statistics.

These statistics were collected by placing a Generic Probe on the Media Access Control (MAC) Statistics module in each link. The MAC Statistics module was used to measure the delay and throughput for all CSMA/CD workstation models on one link. All CSMA/CD workstation model MAC instances share the same memory. Therefore, all the CSMA/CD workstation models write the delay and throughput into one memory. These statistics are then made available to the Post Processor in BONeS by placing a Generic Probe on the MAC Statistics Compute module.



The traffic intensity per node was varied from 10 Kbps to 90 Kbps at twelve points during the simulation. The traffic intensity was varied with an exponential function to show the knees of the curves. The simulation time per iteration was set to one second. The actual computer time to do the simulation was approximately 30 hours on a Sun 600/MP with 128 Megabytes of memory.

## 5. CONCLUSION

At this point, the simulation model has been built, but the simulation tests are not complete. However, some preliminary comments about the network model and the performance of the network are possible at this point. Final conclusions are postponed until more simulation results are available.

### 5.1 Network Expectations

The network should be reliable and have redundant links since the control of the manufacturing will be accomplished over the LAN via APIs. Large amounts of data will be required due to the extensive monitoring and documentation required for the manufacture of the solid rocket motors in the Space Shuttle program.

### 5.2 Network Evaluation Parameters

The two primary evaluation parameters that will be used to judge the network performance are *Throughput* and *Delay*. The Throughput is the effective bit rate of the system in bits per second (bps). It does not include the overhead bits used by the protocol or the packets that have to be retransmitted. The Delay in a LAN is determined by the mean delay per packet. This mean delay per packet will be used to calculate the time to transmit a graphics page.

The delay in a LAN is mostly caused by the following three factors : the propagation delay, the delay in a transceiver, and the queuing delay in a bridge. Also the user response time will be important. These delays are modeled using several different techniques in the simulation.

#### 5.2.1 Propagation Delay

The propagation delay of the light signal traveling down the fiber will be modeled by using a *fixed delay* model provided by BONEs. The link delay will be calculated by

dividing the distance by the speed at which the light travels down the fiber (0.67 times the speed of light).

### **5.2.2 Delay In A Transceiver**

The worst case collision detection time of a particular CSMA / CD commercial transceiver was found to be 900 nanoseconds [15–16]. The worst case packet delay of a particular commercial optical hub was found to be 630 nanoseconds [17]. This delay is caused by the optical-to-electrical and electrical-to-optical conversion. These delays are also modeled by a fixed delay in the simulation.

### **5.2.3 Queue Delay In A Bridge**

In the simulation model each of the CSMA / CD networks will be connected to the FDDI backbone by a bridge. A bridge converts the CSMA / CD packet to an FDDI packet and buffers the incoming packets until they are serviced. If a packet enters the bridge and the queue is full, the packet is discarded. If the queue is large but not full, then the packet will not be discarded, but it will be delayed.

## **5.3 Mean Delay and Throughput Plots**

The mean delay per packet versus the offered traffic intensity plots are shown in figures 5.1, 5.2, and 5.3. The throughput versus the offered traffic intensity plots are shown in figures 5.4, 5.5, and 5.6.

## BIS Network Delay Comparison Plot

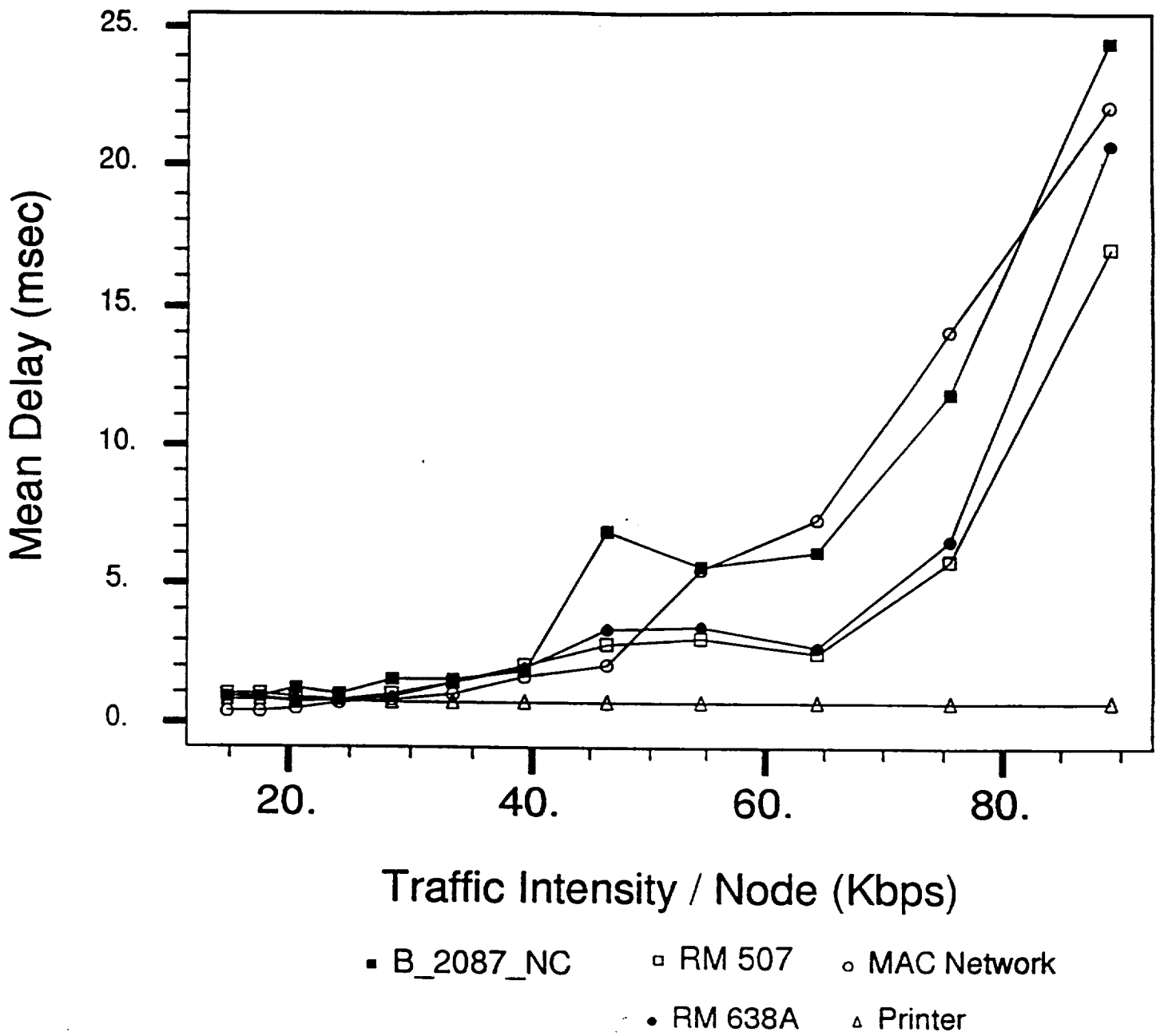


Figure 5.1 BIS Network Delay Comparison Plot

## Non-Intensive Network Delay Comparison Plot

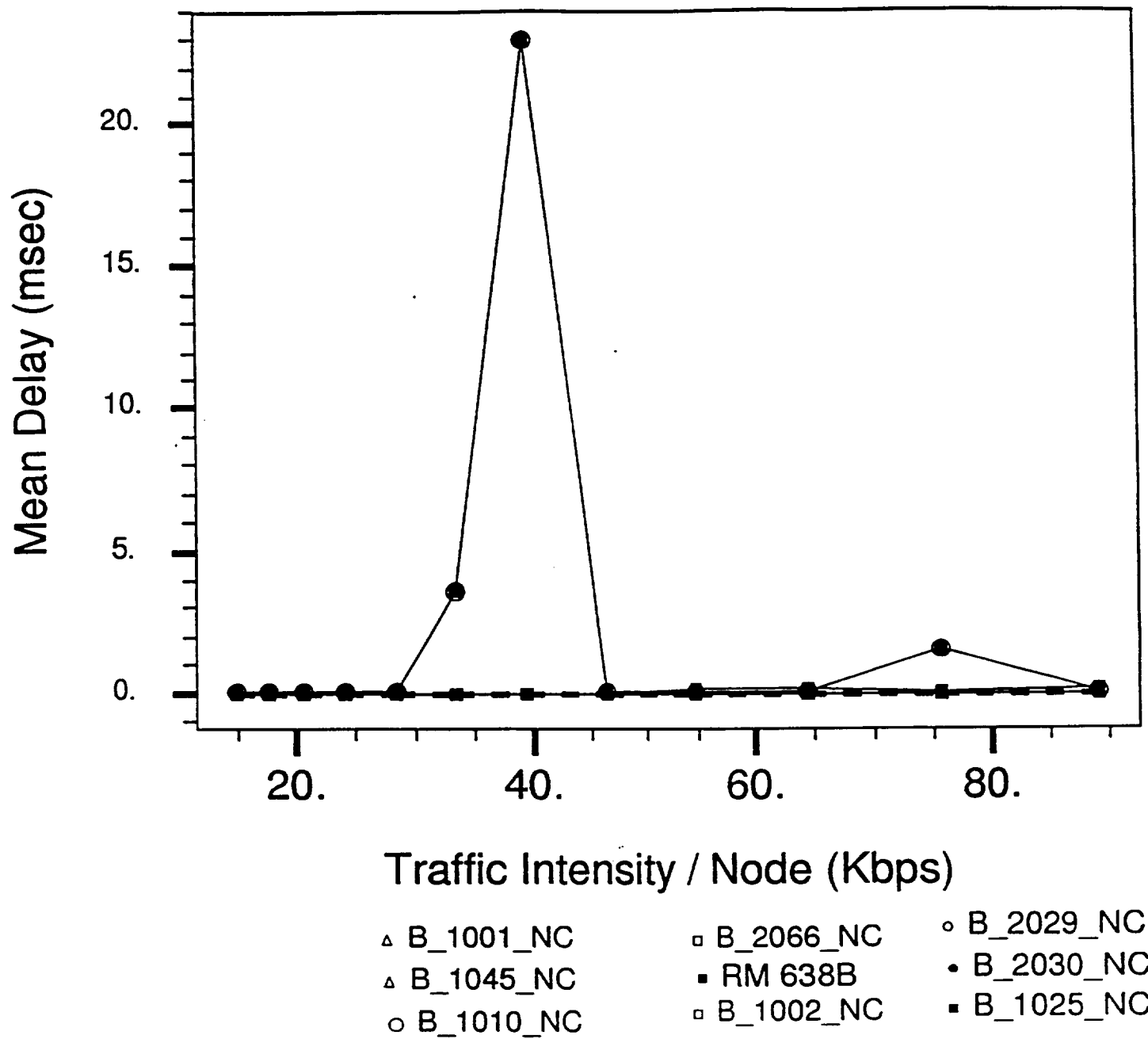


Figure 5.2 Non-Intensive Network Delay Comparison Plot

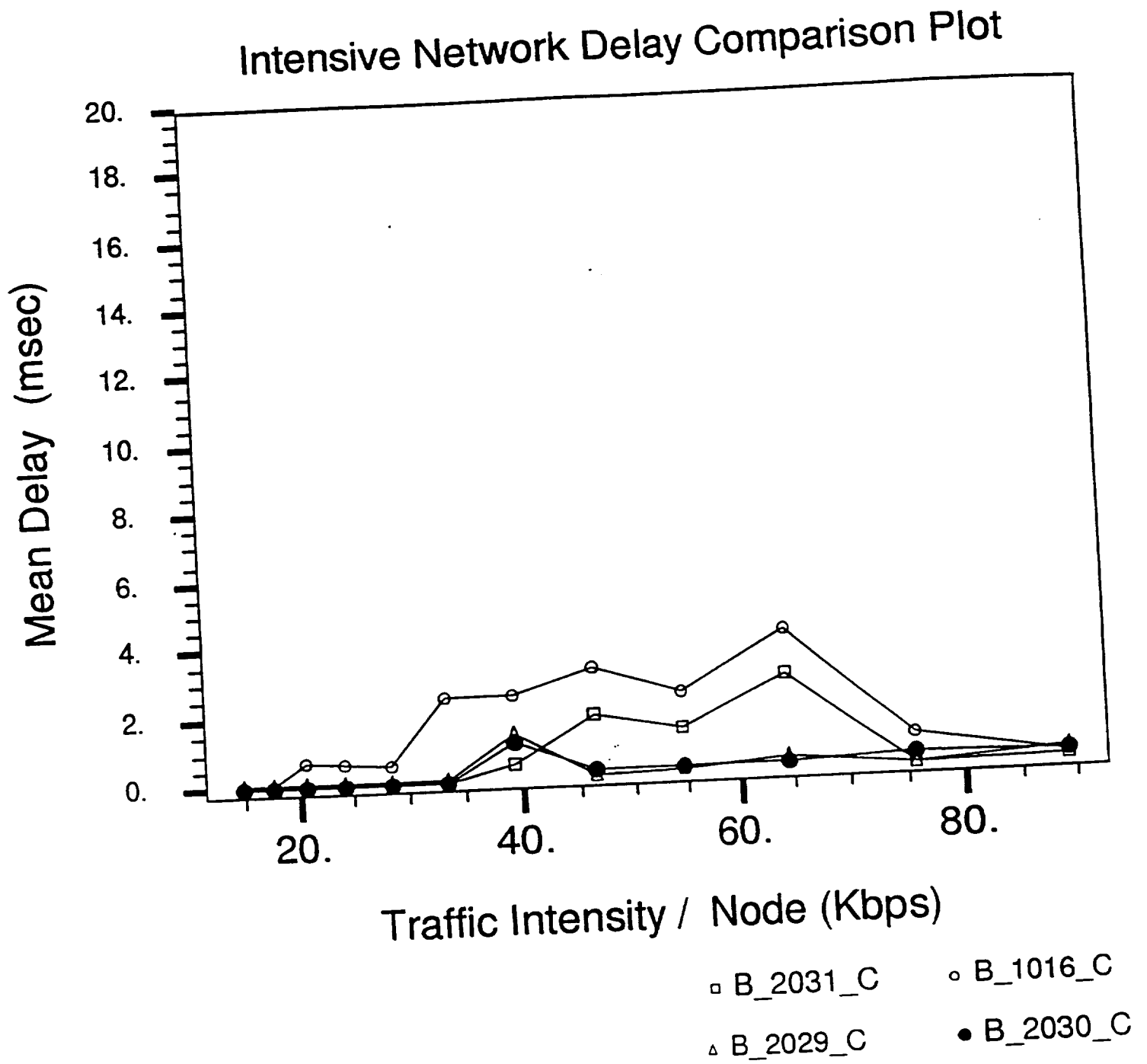


Figure 5.3 Intensive Network Delay Comparison Plot

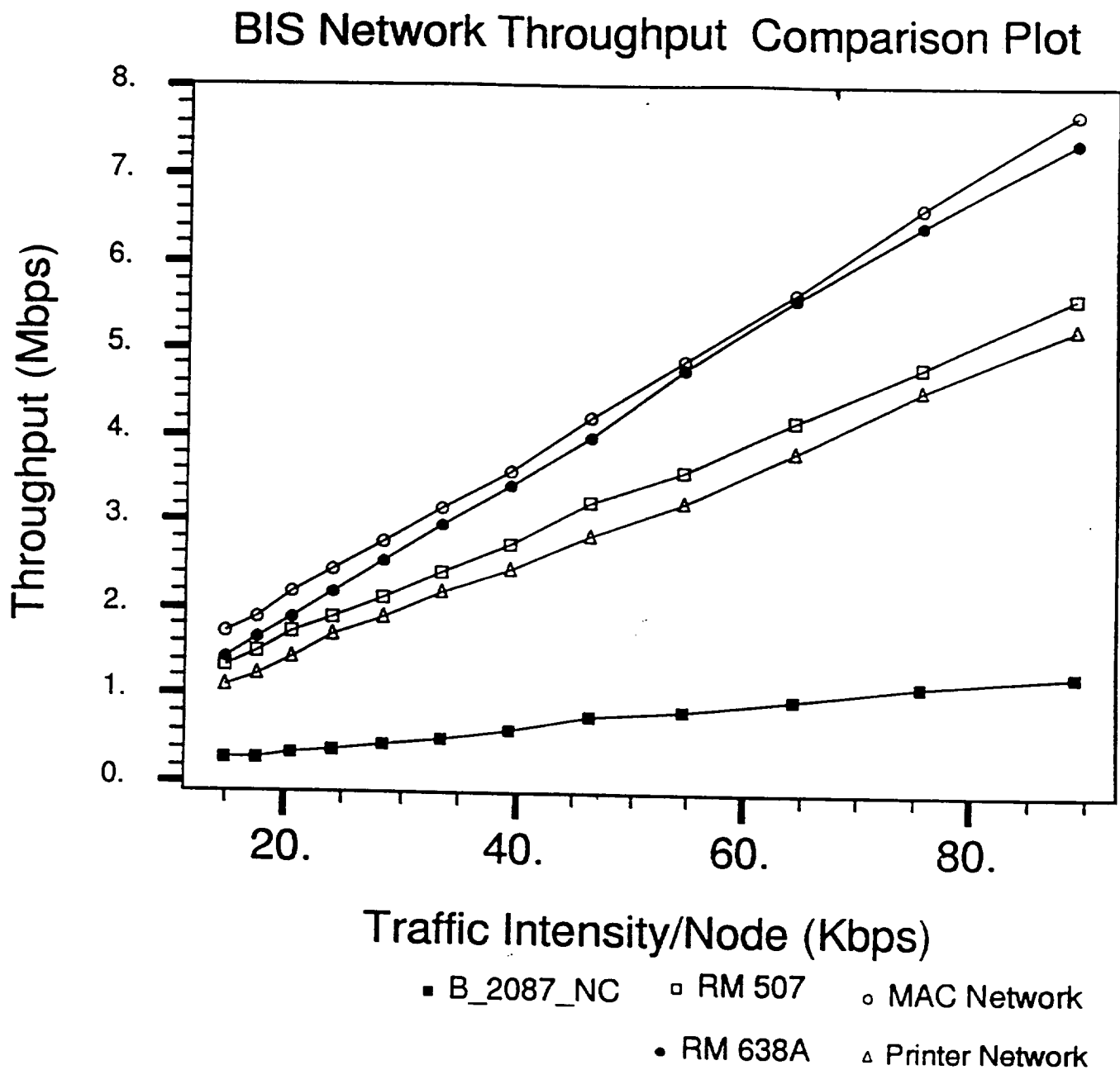


Figure 5.4 BIS Network Throughput Comparison Plot

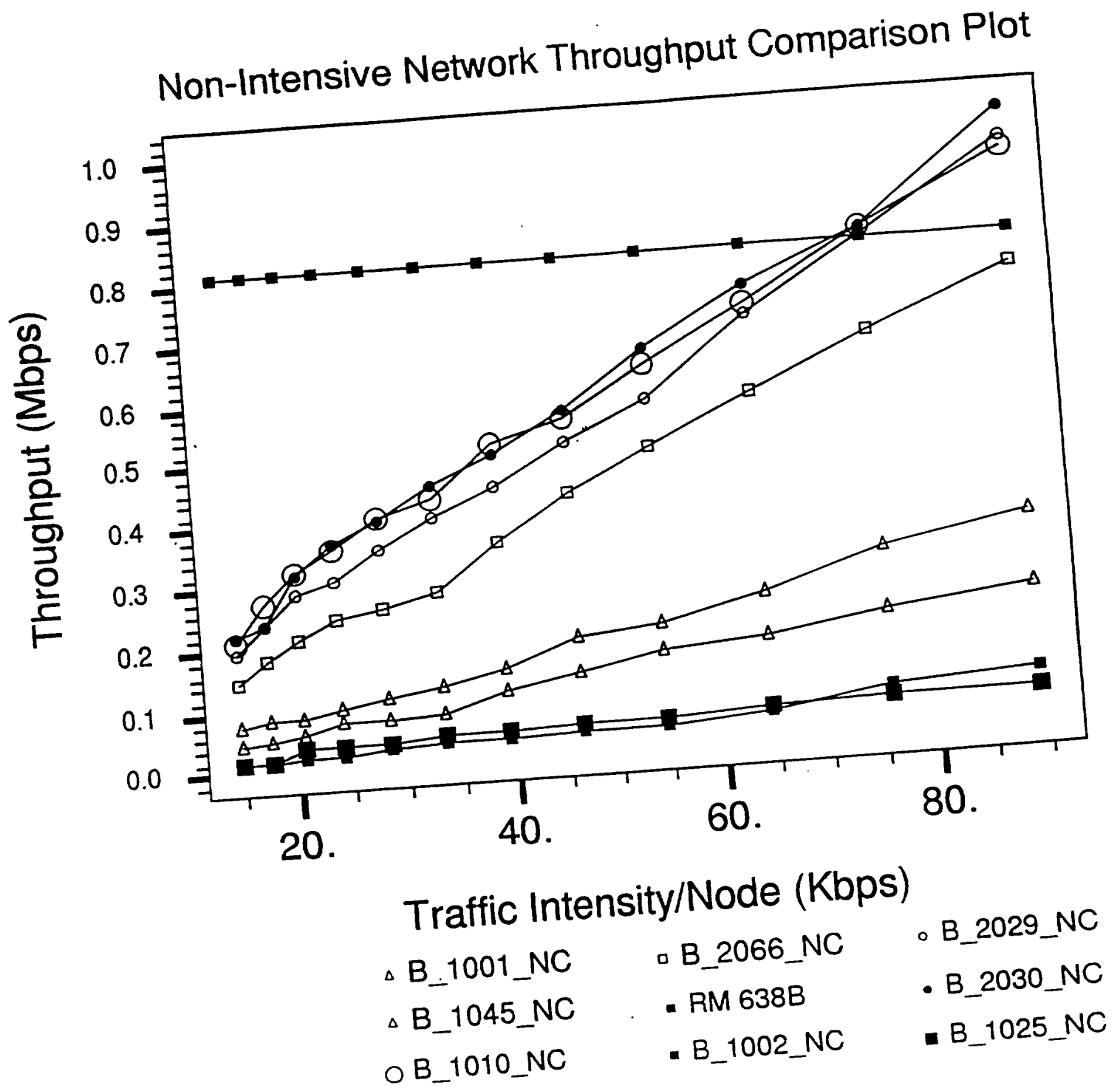


Figure 5.5 Non-Intensive Network Throughput Comparison Plot



Intensive Network Throughput Comparison Plot

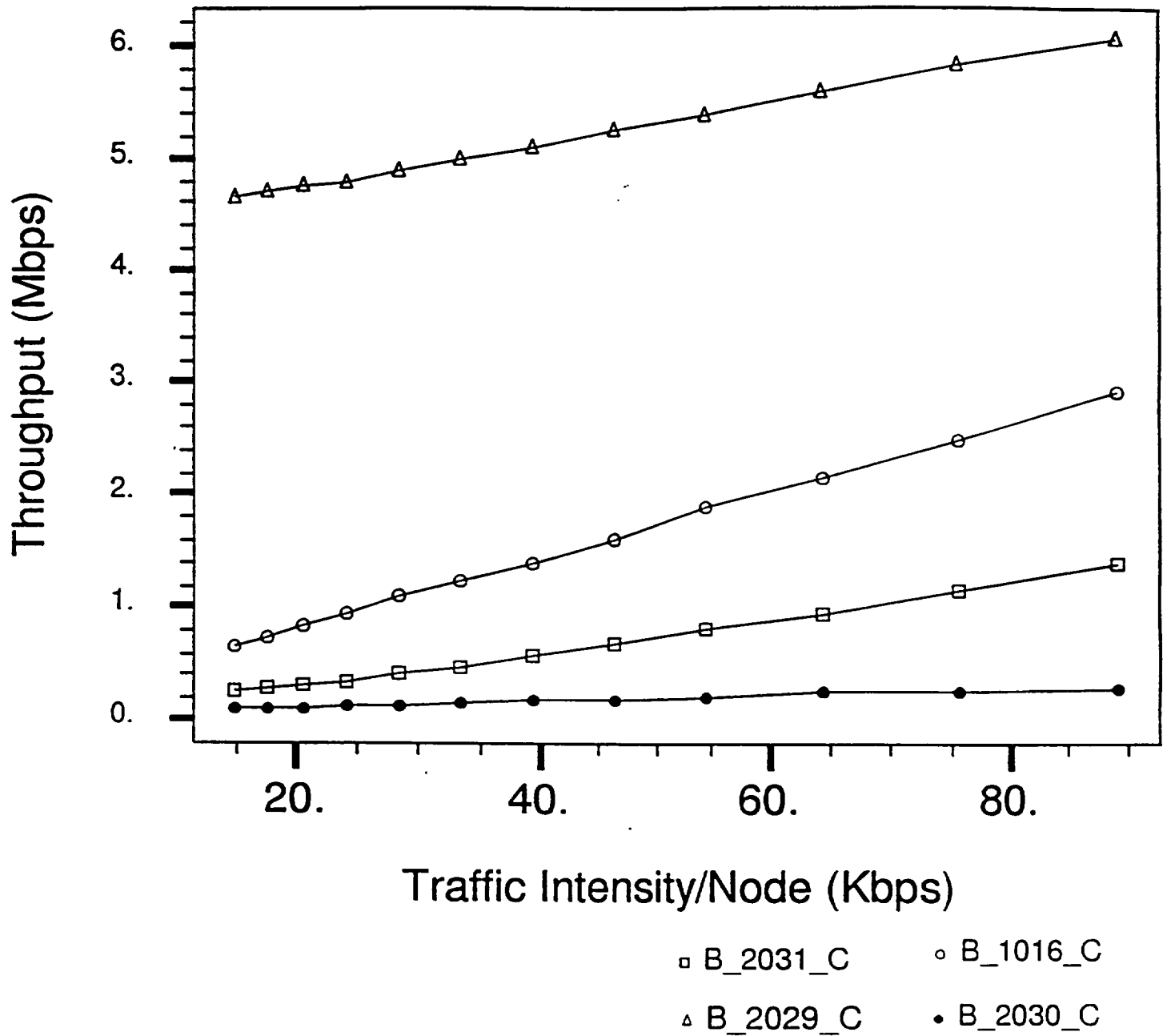


Figure 5.6 Intensive Network Throughput Comparison Plot

## 5.4 Observations and Results from the Plots

The statistics collected with the probes during the simulation were plotted to judge the performance of the network. The mean delay per packet and throughput were plotted versus the offered traffic intensity. These plots were created using the Post Processor in BONEs and show the performance of the network at each iteration of the traffic intensity during the simulation.

### 5.4.1 Mean Delay Plots

The mean delay per packet versus the offered traffic intensity plots are shown in figures 5.1, 5.2, and 5.3. The BIS devices delay plot shows a rising curve; the OIS devices (Intensive and Non-Intensive) delay plot shows a knee curve.

In the case of the BIS devices plot, the mean delay per packet increases as the offered traffic intensity increases. The delay curves level out close to a traffic intensity of 35 Kbps per node and then start to climb linearly. This agrees with the generally accepted assumption that a CSMA/CD network overloads at somewhere between 30% and 50% of its maximum transmission speed. Note that the transmission speed of a link (10 Mbps for Ethernet) equals the traffic intensity per node times the number of nodes. There are approximately 100 nodes per link in the BIS section; 100 nodes transmitting at 35 Kbps is 3.5 Mbps. The simulation only calculates delays per packet for successful packet transmissions and does not include lost packets.

In the case of the OIS devices, all the links show a knee at a particular traffic intensity. The mean delay per packet decreases beyond this traffic intensity, because the number of completed packets beyond the knee of each link decreases. Even though the traffic intensity is being increased, many nodes are not given access to the channel. The packets that do get through have a smaller delay because the mean delays are only calculated for successful transmissions of the packets in the

simulation. This shows that the links are overloaded and only a few nodes can communicate. All other nodes are locked out by the excessive traffic.

#### **5.4.2 Throughput Plots**

The throughput versus the offered traffic intensity plots are shown in figures 5.4, 5.5, and 5.6. The BIS and OIS devices throughput plot shows a rising curve.

The curves in these figures show that the throughput increases linearly with the offered traffic intensity per node. But the analysis of the mean delay per packet shows that the links are overload beyond a certain traffic intensity. This is because only a few nodes are able to transmit and all others cannot. The throughput beyond this knee is only available to a few nodes. So the throughput for each of the links is compared at the traffic intensity where the maximum delay per packet occurred.

#### **5.5 Validation of the Simulation Model**

Any simulation model must be validated before the results can be accepted. The BONEs modules developed for simulation were checked with the site engineers at ASRM for the validation of the modules. The results now need to be validated by running the simulation for different iterations, with a different global seed (initial state), and by running the simulation for different time periods.

#### **5.6 Preliminary Conclusions**

This report has introduced the basic operating characteristics of the network installed at the ASRM site located in Iuka, Mississippi. An overview of the network topology, communication protocols, and hardware devices used was presented.

The main objective of the research was to model, simulate, and analyze the network to determine its performance. The two primary evaluation parameters used to judge the network performance were the throughput and the delay.

From the results obtained thus far it can be concluded that,

1. For the BIS devices the mean delay per packet increases as the offered traffic intensity increases. While for the OIS devices all the links show a knee at a particular traffic intensity.
2. The throughput for all the sub-networks increases linearly with the traffic intensity per node.
3. Amongst all the sub-networks the Intensive buildings experiences the lowest mean delays.
4. From the delay plots it can be seen that the BIS network is the most heavily loaded network. This can be attributed to 400 Macintosh workstations connected to the BIS.
5. The buffer capacity of the bridges does appear to produce a bottleneck for the network.
6. The FDDI backbone ring seems to provide ample bandwidth as was expected.
7. The FDDI backbone causes only a negligible delay compared to other delay-causing factors considered in section 5.2.

## 5.7 Future Work

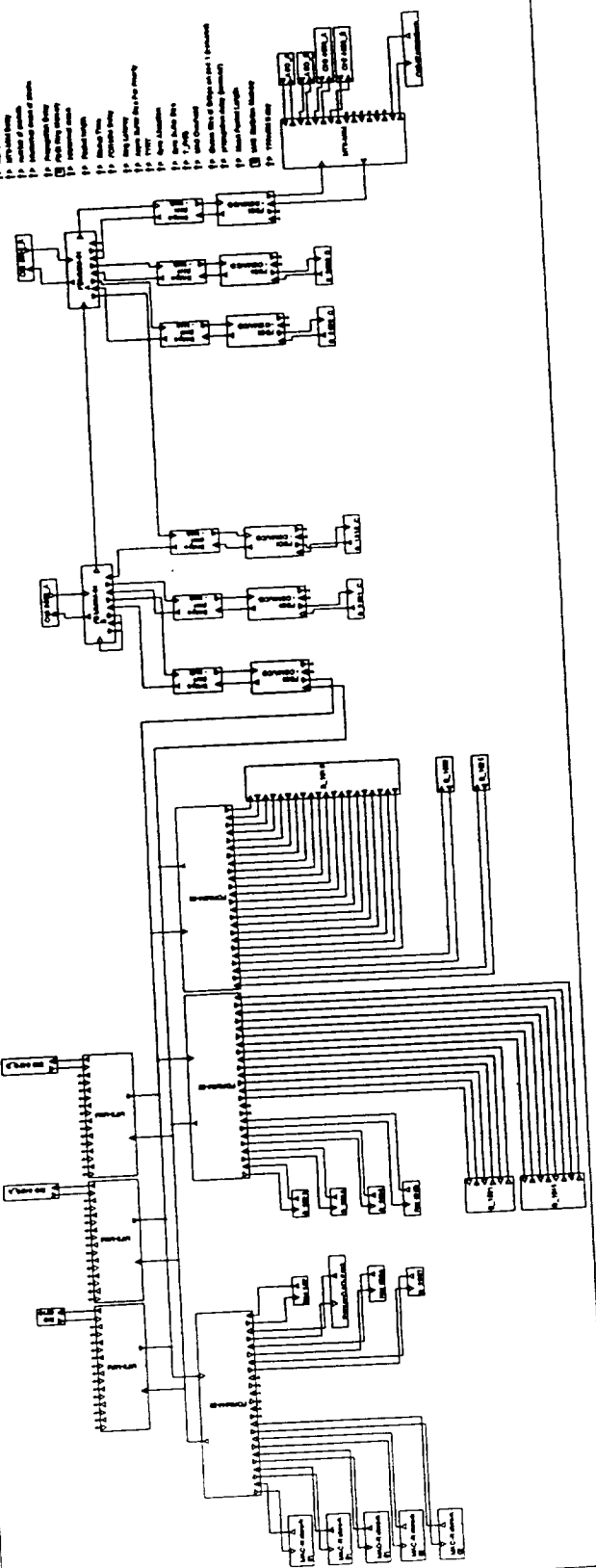
Not intended to be a complete analysis, this report provides the basic concepts by which the ASRM network will be evaluated. Future plans include a more detailed analysis of the network through computer simulation. Parameters such as traffic density, packet size, and response times will be varied in order to gain a more accurate and diverse analysis of network performance.

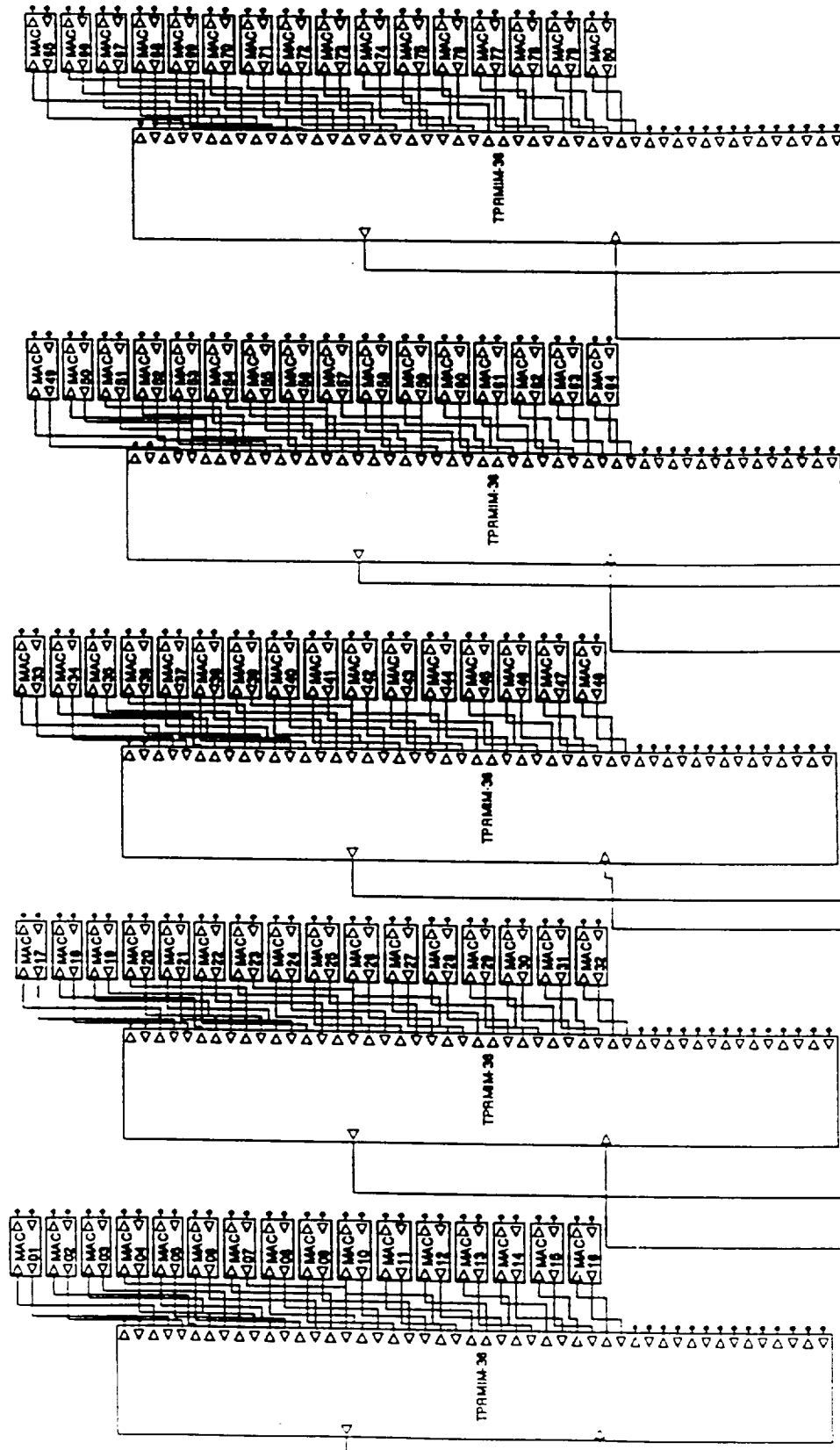
As of this point in time, the Cabletron hubs used to connect the individual networks have been modeled in BONEs as constant delays. Future plans include a detailed analysis of the Cabletron hubs. It is hoped that this analysis will allow a more precise and accurate model for the BONEs simulator to be built. In so doing, the results produced by the computer simulation will hopefully approach a higher degree of accuracy.

## **APPENDIX**

### **A1 BONeS Modules**

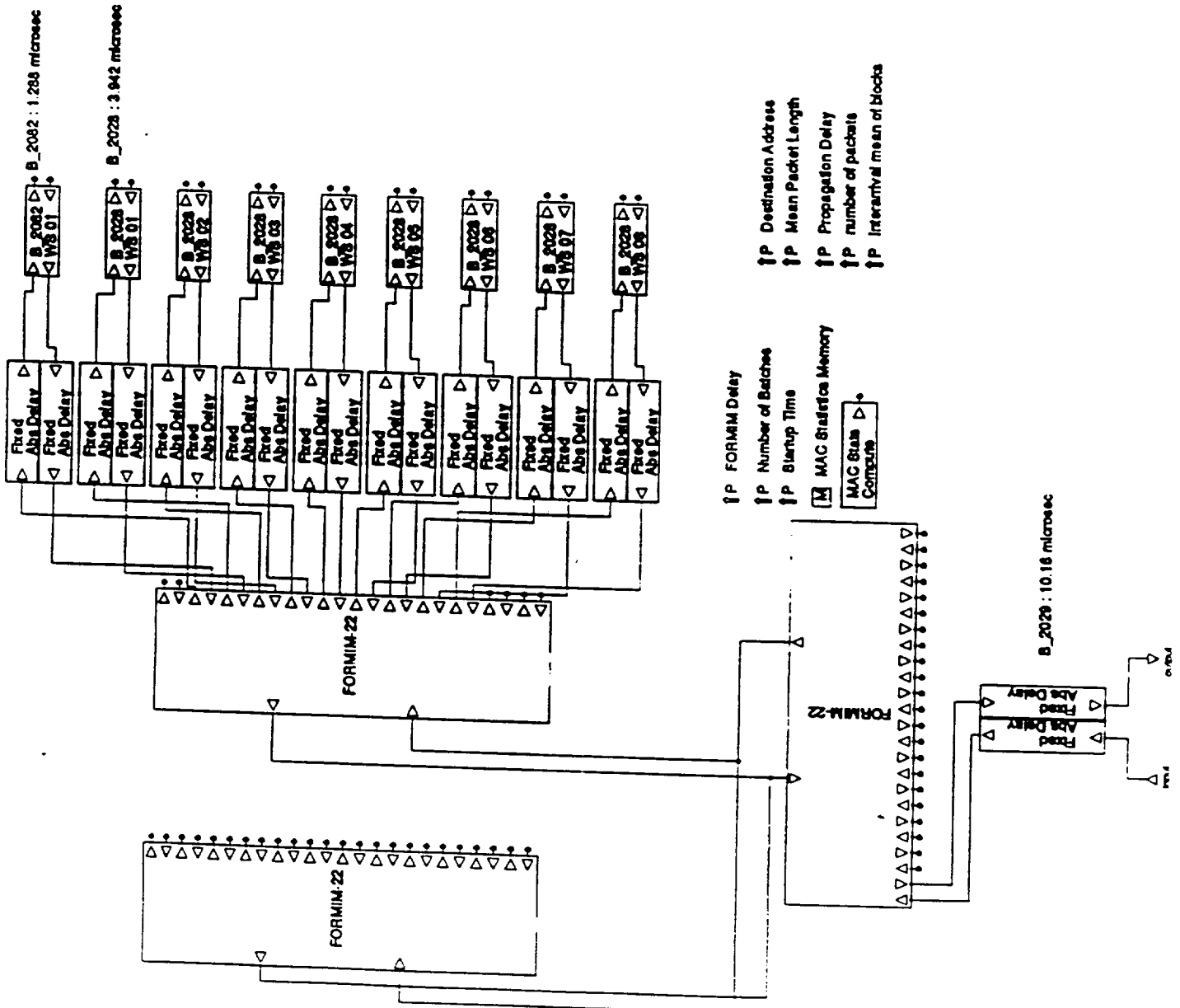
- 1-1. Interconnect Queue Size
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- 1-99. Interconnect Queue
- 1-100. Interconnect Queue



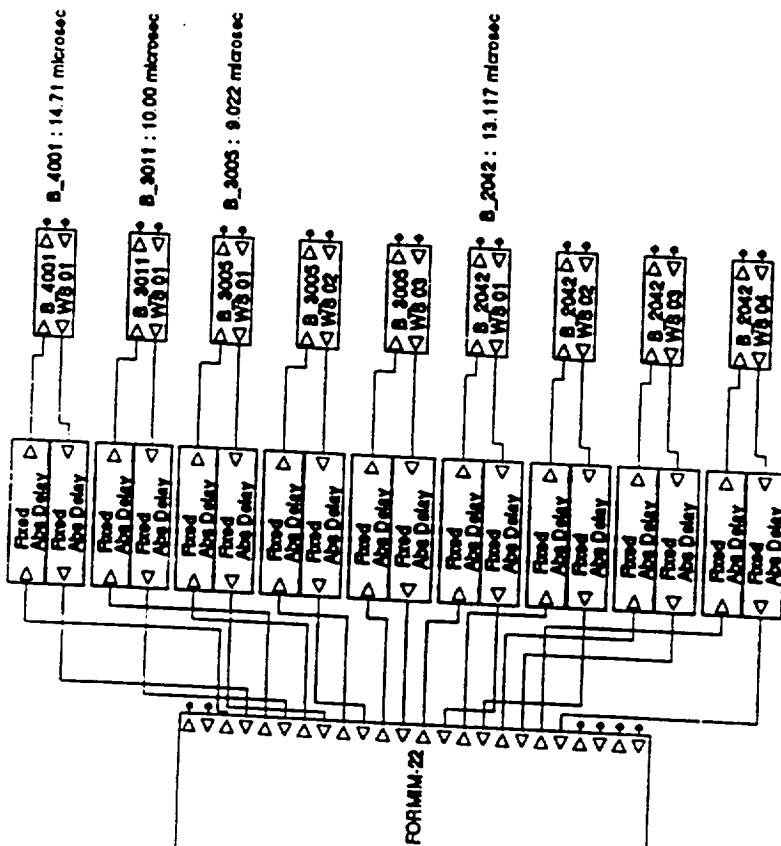


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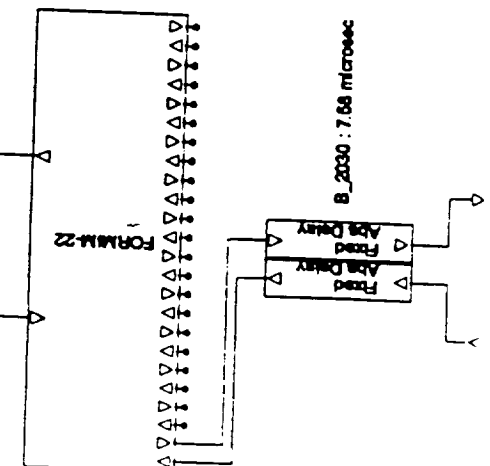
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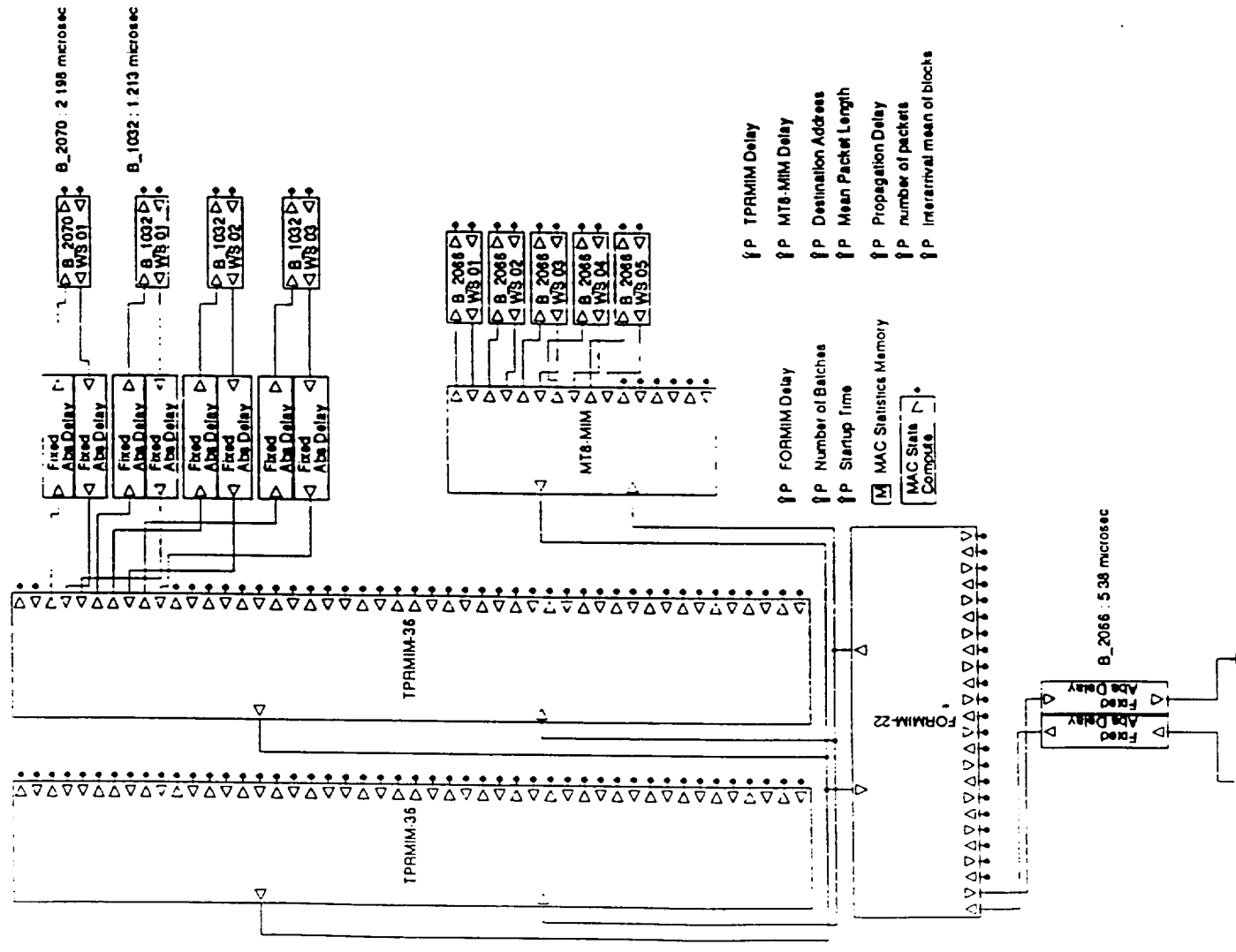




- ↑ P FORMIM Delay
- ↑ P Destination Address
- ↑ P Number of Batches
- ↑ P Mean Packet Length
- ↑ P Startup Time
- ↑ P Propagation Delay
- ↑ P MAC Statistics Memory
- ↑ P number of packets
- ↑ P Interval mean of blocks
- MAC Stats Compute

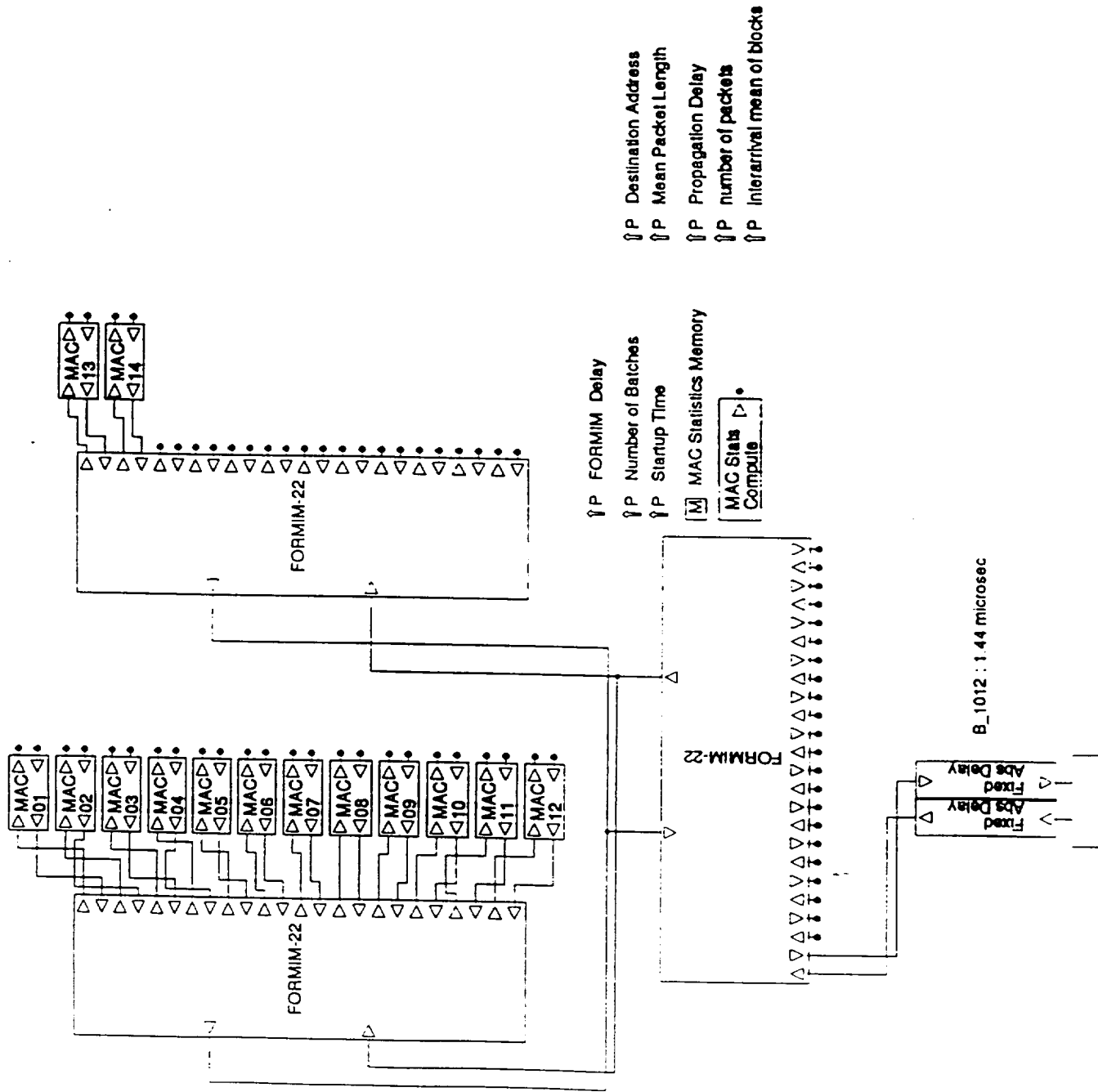


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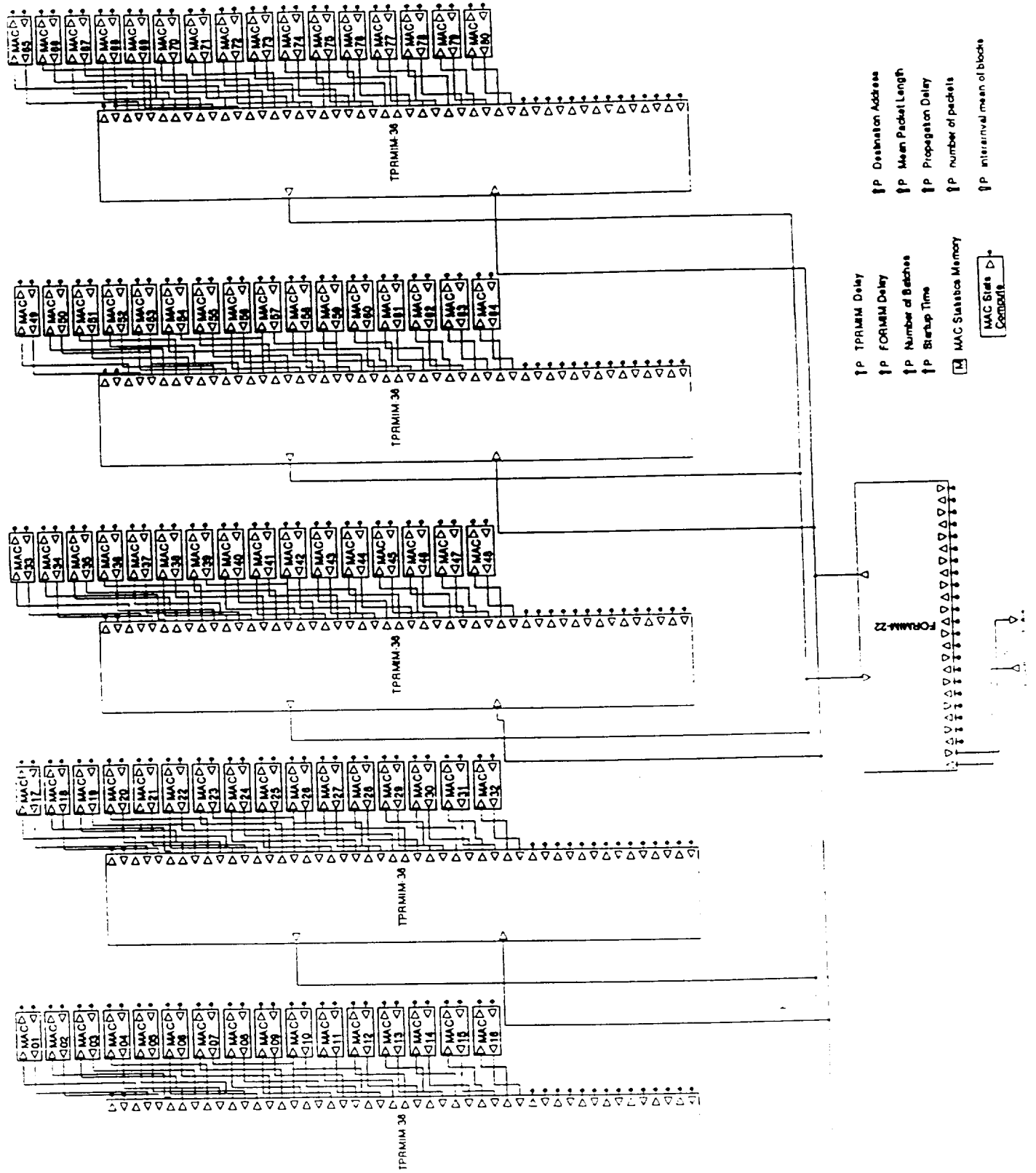


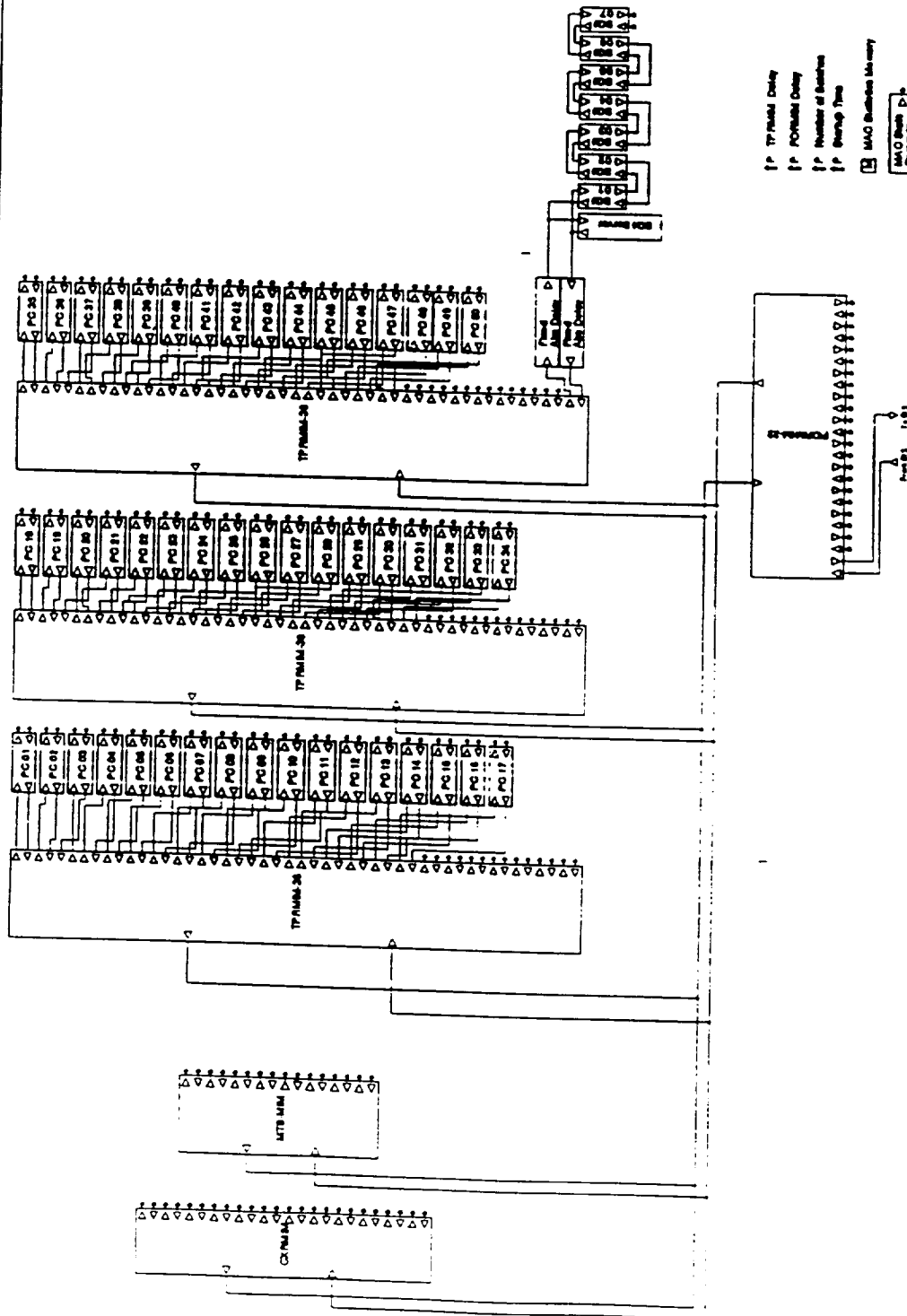
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B\_2087 [21-Apr-1993 0:18:42]



INM 6.0/A [22 Apr 1993 2:51:11]





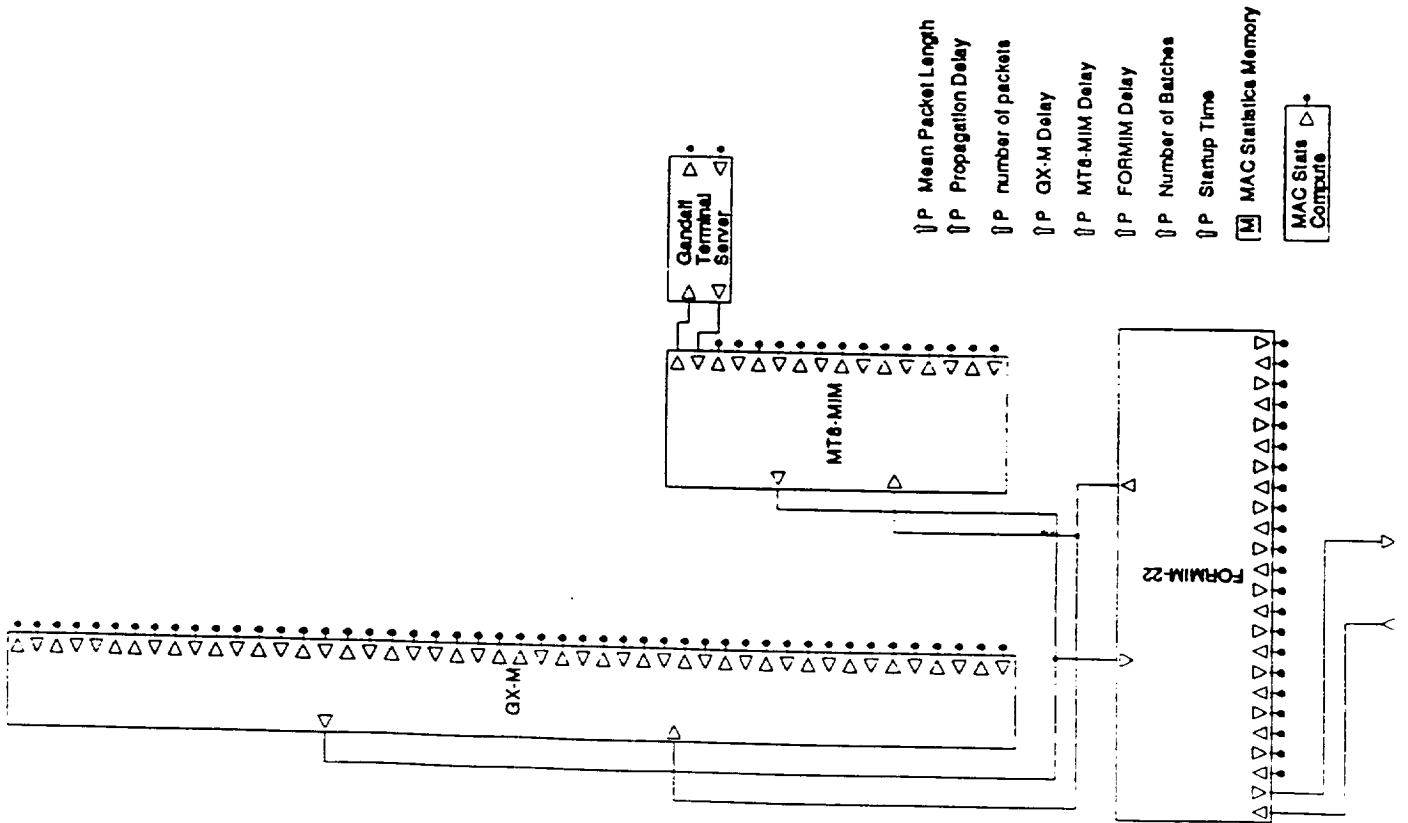
- [P] MTS-MM Delay
- [P] CEN-MM Delay
- [P] Distribution Address
- [P] Mean Packet Length
- [P] Propagation Delay
- [P] Number of packets
- [P] Interarrival mean of blocks
- [P] Interarrival mean of B/B

- [P] TP Field Delay
- [P] PO Field Delay
- [P] Number of Buffers
- [P] Storage Time
- [P] MAC Subsystem Memory
- [P] MAC Subsystem Control

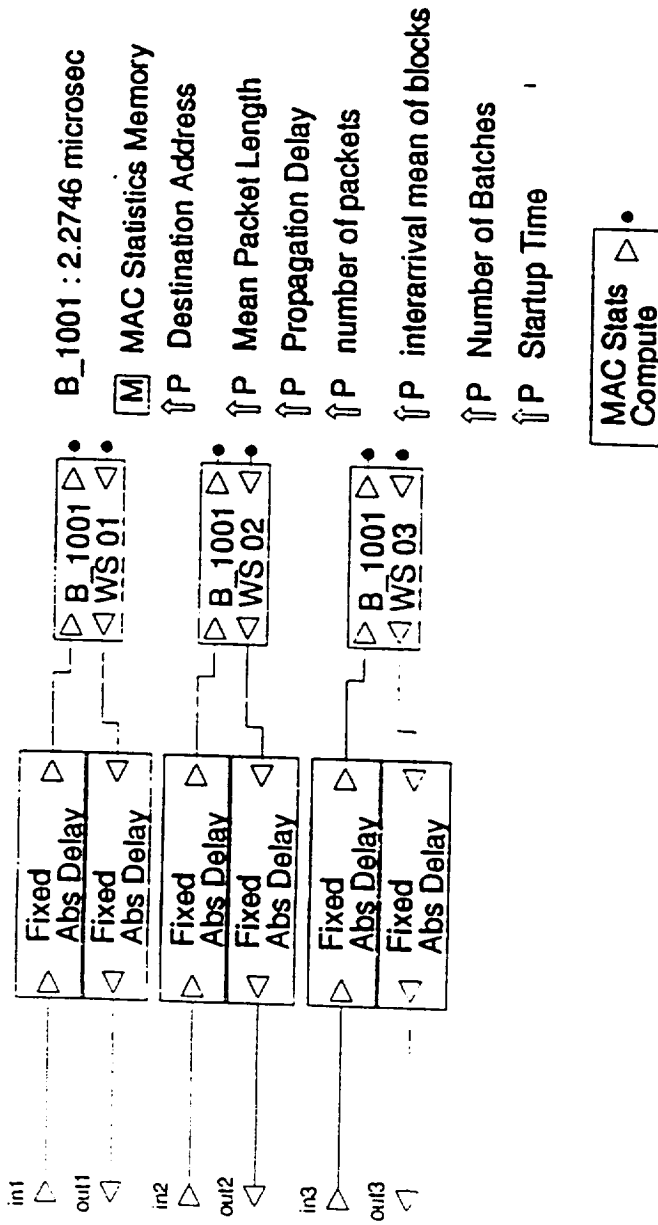
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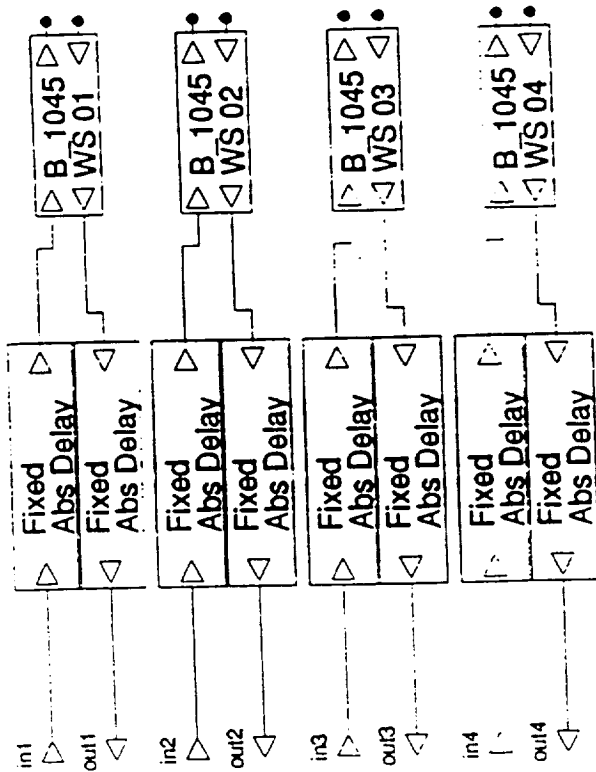
B\_1001 [ 22-Apr-1993 2:47:09 ]



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B\_1045 [ 22-Apr-1993 2:46:45 ]

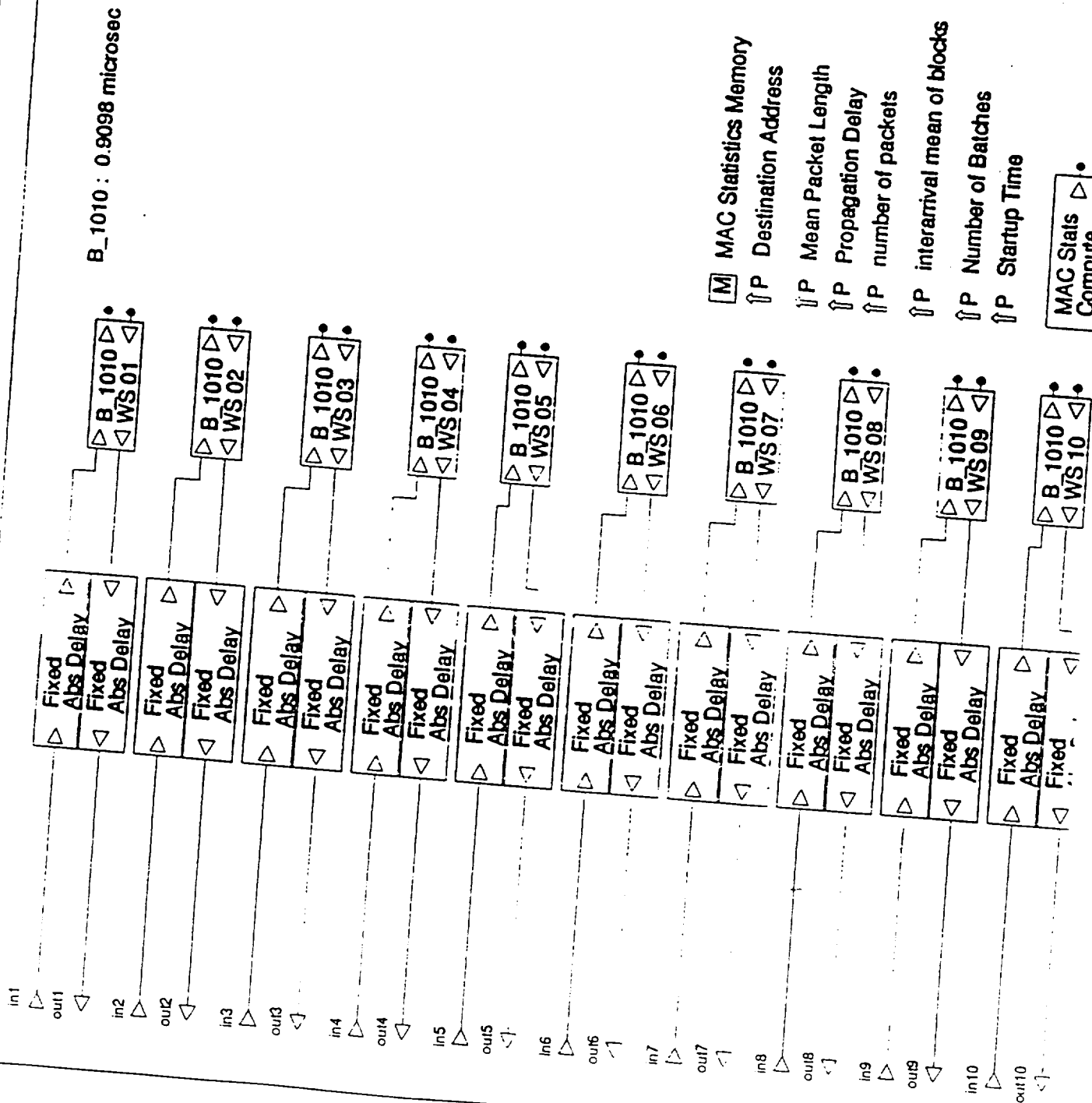


B\_1045 : 2.27 micro sec  
[M] MAC Statistics Memory  
↑P Destination Address  
↑P Mean Packet Length  
↑P Propagation Delay  
↑P number of packets  
↑P interarrival mean of blocks  
↑P Number of Batches  
↑P Startup Time

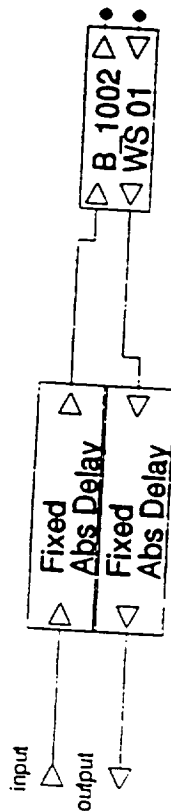
MAC Stats Compute

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B\_1010 [ 22-Apr-1993 2:44:53 ]



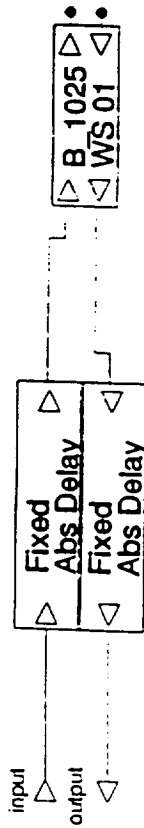
B\_1002 [ 22-Apr-1993 2:45:30 ]



**[M]** MAC Statistics Memory  
↑ P Destination Address  
↑ P Mean Packet Length  
↑ P Propagation Delay  
↑ P number of packets  
↑ P interarrival mean of blocks  
↑ P Number of Batches  
↑ P Startup Time

MAC Stats  
Compute

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B\_1025 : 3.639 microsec

**[M] MAC Statistics Memory**

↑ P Destination Address

↑ P Mean Packet Length

↑ P Propagation Delay

↑ P number of packets

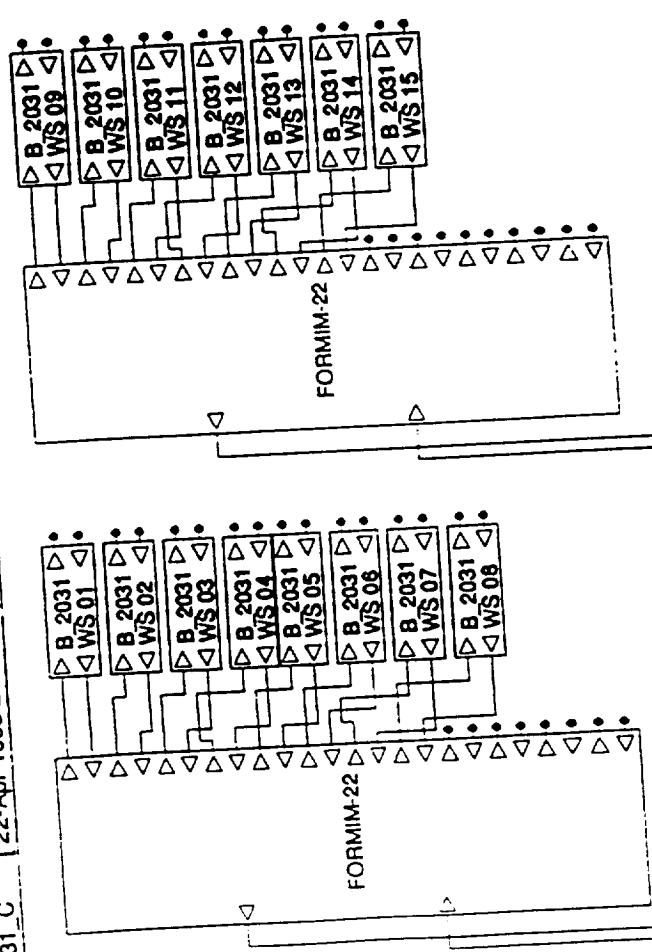
↑ P interarrival mean of blocks

↑ P Number of Batches

↑ P Startup Time

**MAC Stats**  
**Compute**

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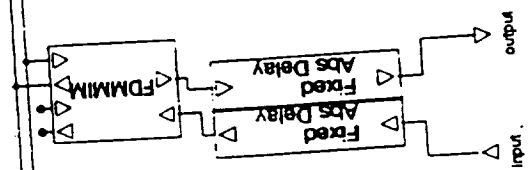
- ↑ P Destination Address
- ↑ P Mean Packet Length
- ↑ P Propagation Delay
- ↑ P number of packets
- ↑ P interarrival mean of blocks

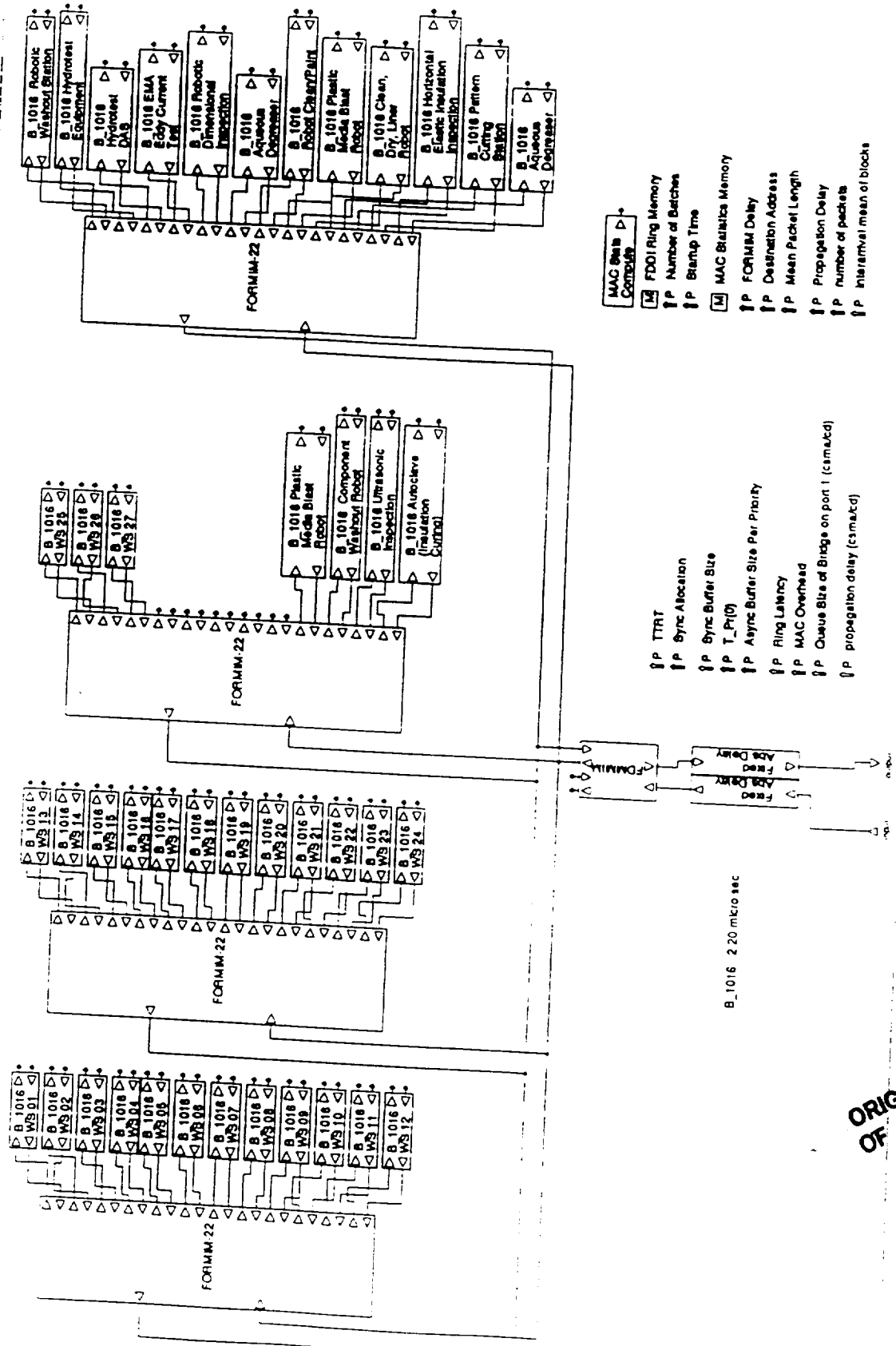
MAC Stats  
Compute

- ↑ P Number of Batches
- ↑ P Startup Time
- MAC Statistics Memory
- ↑ P FORMIM Delay

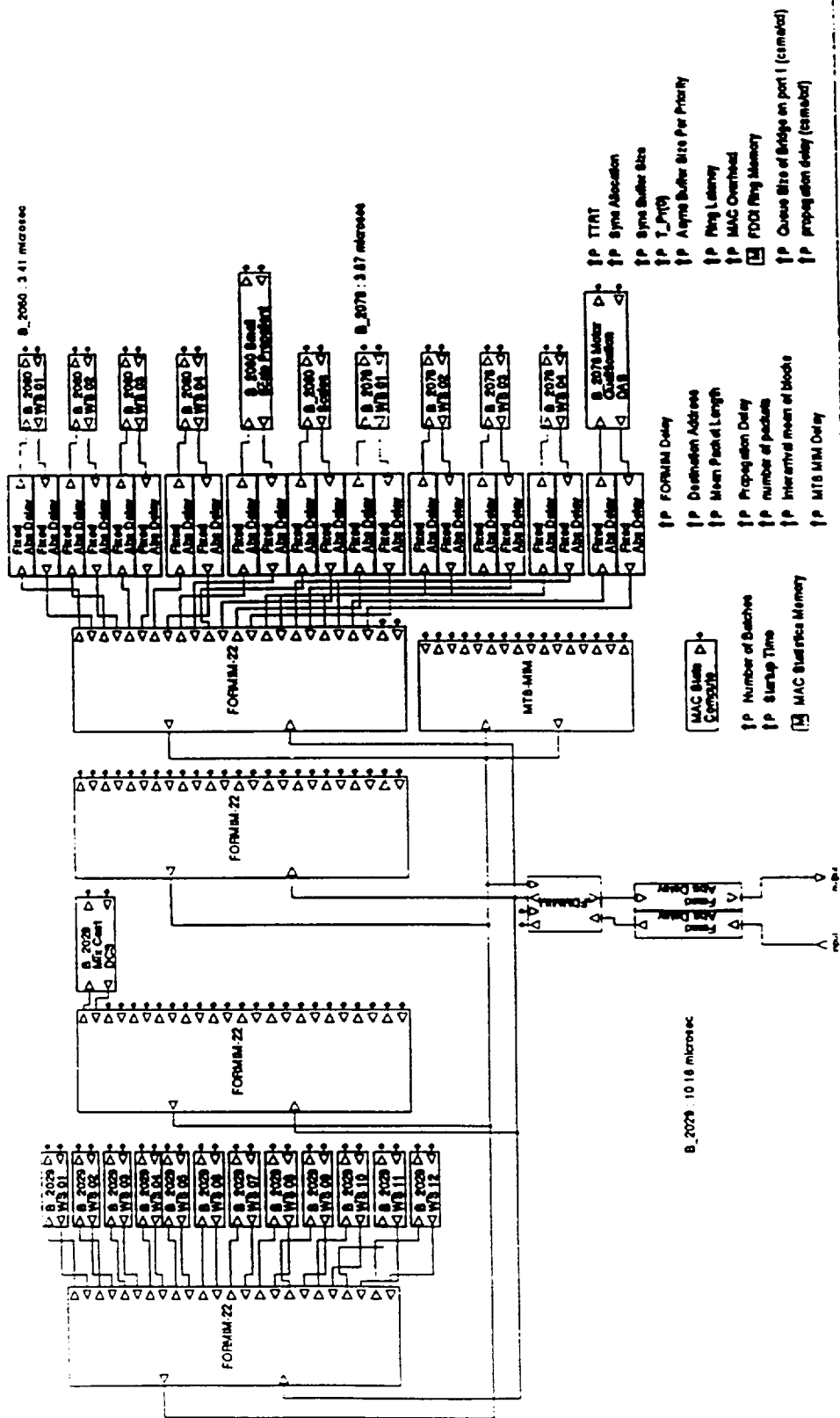
- ↑ P TTRI
- ↑ P Sync Allocation
- ↑ P Sync Buffer Size
- ↑ P T\_Pr(0)
- ↑ P Async Buffer Size Per Priority
- ↑ P Ring Latency
- ↑ P MAC Overhead
- MAC FDDI Ring Memory
- ↑ P Queue Size of Bridge on port 1 (csma/cd)
- ↑ P propagation delay (csma/cd)

B\_2031 : 7.05 microsec



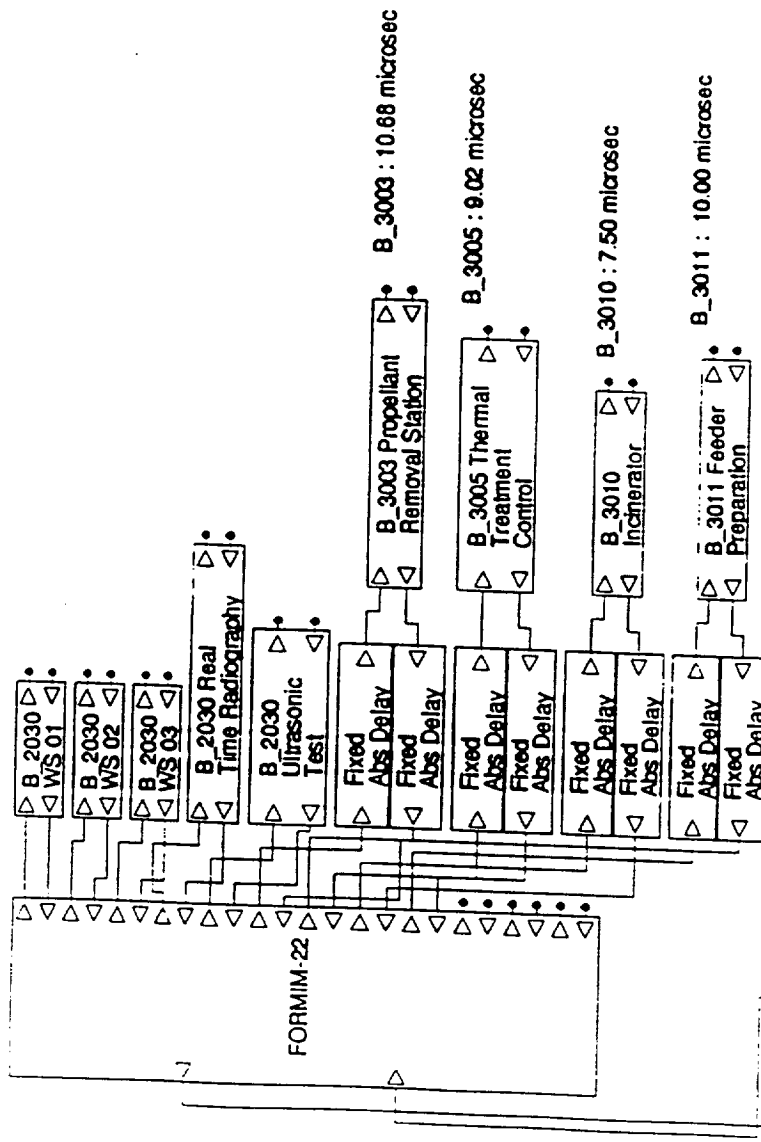


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B\_2030\_C [ 22-Apr-1993 21:24:48 ]



MAC Stats Compute

↑ P Number of Batches  
↑ P Startup Time

MAC Statistics Memory

FDDI Ring Memory

↑ P TTRT

↑ P Sync Allocation

↑ P Sync Buffer Size

↑ P T\_Pr(0)

↑ P Async Buffer Size Per Priority

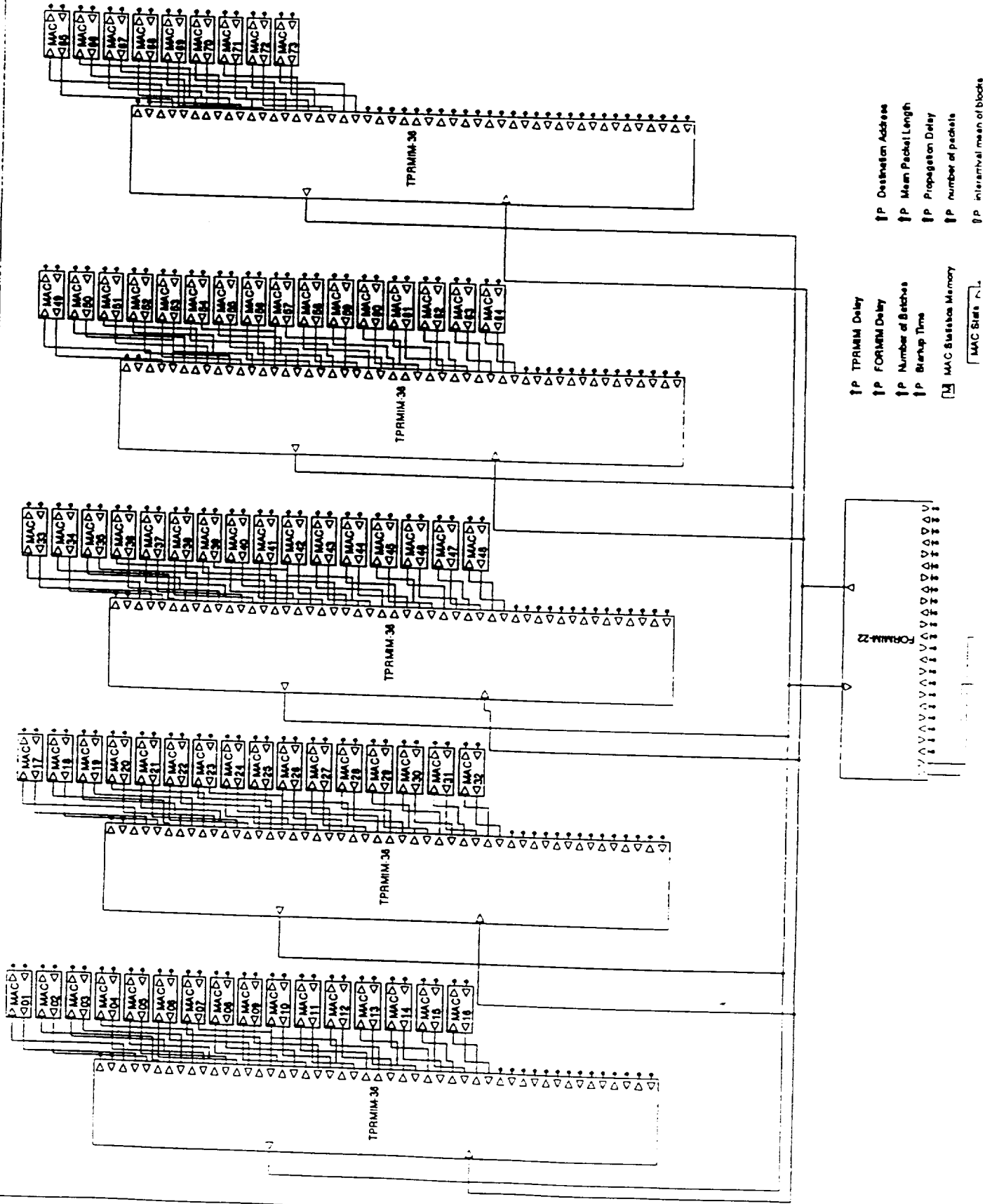
↑ P Ring Latency

↑ P MAC Overhead

↑ P Queue Size of Bridge on port 1 (csma/cd)

↑ P FORMIM Delay  
↑ P Destination Address  
↑ P Mean Packet Length  
↑ P Propagation Delay  
↑ P number of packets





## **GLOSSARY**

<b>ADI</b>	<b>Asynchronous Data Interface</b>
<b>API</b>	<b>Application Program Interface – Provided by RUST</b>
<b>ASC</b>	<b>Area Supervisory Computers</b>
<b>AUI</b>	<b>Access Unit Interface</b>
<b>BAS</b>	<b>Building Automation System</b>
<b>BIS</b>	<b>Business Information System</b>
<b>B_1000</b>	<b>Building 1000</b>
<b>BSGW</b>	<b>BASEstar Gateway</b>
<b>CAD</b>	<b>Computer Aided Design</b>
<b>CCTV</b>	<b>Closed Circuit Television</b>
<b>DAS</b>	<b>Device Access Software</b>
<b>DCS</b>	<b>Device Control Software</b>
<b>DHI</b>	<b>Data Highway Interface</b>
<b>FALS</b>	<b>Fire And Line Safety</b>
<b>FDDI</b>	<b>Fiber Distributed Data Interface</b>
<b>FDLM</b>	<b>Fiber Distributed Line Module</b>
<b>FTP</b>	<b>File Transfer Protocol</b>
<b>GKS</b>	<b>Graphics Kernel System</b>
<b>LSC</b>	<b>Local Supervisory Computers</b>
<b>OIS</b>	<b>Operational Information System</b>
<b>NCT</b>	<b>Network Cooperating Task</b>
<b>NI</b>	<b>Network Interface</b>
<b>PAA</b>	<b>Process Automation Application</b>
<b>PAM</b>	<b>Process Automation Module</b>
<b>PE</b>	<b>Protocol Emulator</b>

PSCNI	Packet-Switched Communication Network-Internet
SR	Security Router
TCP/IP	Transmission Control Protocol/Internet Protocol
UPS	Uninterrupted Power Supply
UTP	Unshielded Twisted Pair
WS	Work-Stream

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